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Fish Production and Movements in the Lower Logan River, Utah

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FISH PRODUCTION AND MOVEMENTS IN THE LOWER

LOGAN RIVER, UTAH

by

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of the requirements for the degree

of

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Eric P. Bergersen

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ABSTRACT

Fish Production and Movements in the Lower
Logan River, Utah

by

Eric P. Bergersen, Doctor of Philosophy

Utah State University, 1973

Major Professor: Dr. John M. Neuhold
Department: Wildlife Resources

Following the abatement of domestic sewage pollution in the lower Logan River, the fish population was investigated in terms of abundance, growth, fecundity, production, mortality, age class structure, species diversity, distribution and movements during 1970 and 1971.

Three general groupings of fish were identified in the study area on the basis of species composition, abundance and distribution using a cluster analysis technique. These were located in 1) the tributary stream (7-Mile Creek) which previously transported sewage to the river and 2) above and 3) below 7-Mile Creek in the main stream of the Logan River. A "transition" population was present in the river near the confluence of 7-Mile Creek.

Species diversity was predictable on the basis of four physical variables including percent riffle, a measure of bank cover, stream sinuosity and gradient. Percent riffle

appeared to be the most important variable in predicting the "Trophic Condition Index" of the fish population.

An information theory function was used to determine the extent of fish movement within the study area. Of the four dominant species in the river (carp, mountain whitefish, Utah suckers and brown trout) only the brown trout demonstrated an apparent response to the pollution abatement by reducing the extent of its movements at this time.

Seasonal growth patterns were strikingly similar among the species examined with maximum growth occurring during the spring months. Extensive weight losses, attributed to high population densities and a decline in the invertebrate forage base, occurred during the summer of both 1970 and 1971, particularly in the older age classes of mountain whitefish and brown trout.

Production of carp, mountain whitefish and brown trout and Utah suckers was assumed to approximate total fish production in the river. Whitefish production above and below 7-Mile Creek was estimated to be 3.87 and 1.65 $gm/m^2/yr$ respectively for the period June 1970 to May 1971. Carp production in these two areas was estimated to be 22.86 and 10.45 $gm/m^2/yr$ for the same period. Brown trout production was estimated to be 5.94 $gm/m^2/yr$ above 7-Mile Creek while production of Utah suckers in the study area was estimated to be 2-3 $gm/m^2/yr$. Weighted production for the

entire study area was estimated to be 23.5 $gm/m^2/yr$. Evidence is presented which suggests that fish production has increased following the pollution abatement.

(183 pages)

INTRODUCTION

Organic pollution of a river can be viewed as the addition of readily available energy to the stream ecosystem (Beers, 1968). When pollution abatement and control measures are initiated on a polluted stream, the aquatic community is immediately deprived of this source of energy and distinct changes in the community structure often occur in response to the changing water quality. The reduced flow of energy can have a decided and profound effect on the organisms inhabiting the stream. The biological productivity of the organisms or explicitly the rate of energy flow through their respective trophic levels can thus be used to determine how the community is responding functionally to the decreased energy supply. By using this fundamental approach to the study of organic pollution it is possible to gain insight into the effects of organic pollution on the aquatic community and the dynamics of the ecological processes involved in the natural recovery of a polluted body of water.

With the emphasis being placed on water pollution abatement and control by numerous federal, state and local agencies, new methods of waste water treatment have been developed and many inadequate treatment systems have been replaced by more efficient and effective methods, reducing the number of lakes and streams receiving untreated domestic pollutants. This in effect has altered the eutrophication processes which had been stimulated by the indiscriminate disposal of sewage in many lakes and streams. In a strict trophic dynamic sense, many waters previously receiving additional nutrients in the form of untreated sewage are now without this energy source. Since the biological recovery of the waterway is the ultimate goal of pollution control, the response of the stream community to this lowered energy supply becomes of interest in gaining an understanding of the processes interacting to bring about this recovery.

The lower Logan River, which was previously an integral part of the Logan, Utah city sewage system, is an example of a river in which the abatement of domestic sewage pollution has occurred.

In November, 1967 the city of Logan began diverting its raw sewage waste water from a system consisting of a small temporary holding pond into a series of large oxidation ponds. This eliminated the raw sewage effluent which was previously allowed to flow untreated from the holding pond down 7-Mile Creek into the valley portion of the Logan River. Prior to this time, the quality of the river water below the confluence of 7-Mile Creek varied with the seasonal changes in the river's flow rate and irrigation demands placed on the water entering the tributary stream. Studies conducted on the valley portion of the river indicated that these seasonal changes in water quality had a predictable influence on the aquatic community (Matthews, 1966; Beers, 1968; Erman, 1968).

This study was an attempt to investigate the effects of the abatement of domestic sewage pollution on the fish population in the valley portion of the Logan River. The main objectives were to compare fish population dynamics in the river above and below the confluence of 7-Mile Creek and to identify changes in fish movement related to the pollution abatement.

DESCRIPTION OF STUDY AREA

The study area was located in the valley portion of the Logan River in Cache Valley (elevation 1350 meters) approximately 5 kilometers west of Logan, Utah. The portion of the river designated as the study area extended downstream a distance of 6.3 kilometers from the Mendon Bridge and included the lower 0.4 kilometers of 7-Mile Creek, a spring fed tributary (Figure 1).

The river above 7-Mile Creek is characterized by swift current, relatively steep gradient (0.57 to 2.73 m/km), numerous distinct riffles and pools, and brushy banks. The stream bottom consists of finely-divided material and some gravel. Except during flooding the water is clear.

The bed of 7-Mile Creek is composed almost entirely of mud and clay. The water in 7-Mile Creek was always turbid during the study.

The physical characteristics of the river change below 7-Mile Creek. The gradient declines (0.40 to 0.23 m/km), the river deepens and widens, water velocities drop to almost undetectable levels, meandering increases and riffle areas are less abundant and are absent from the lower 2 kilometers of the section. Silt carried by 7-Mile Creek increases the turbidity of this section of the river throughout the year. Pertinent chemical and physical features of the study area are presented in Tables 1 and 2.

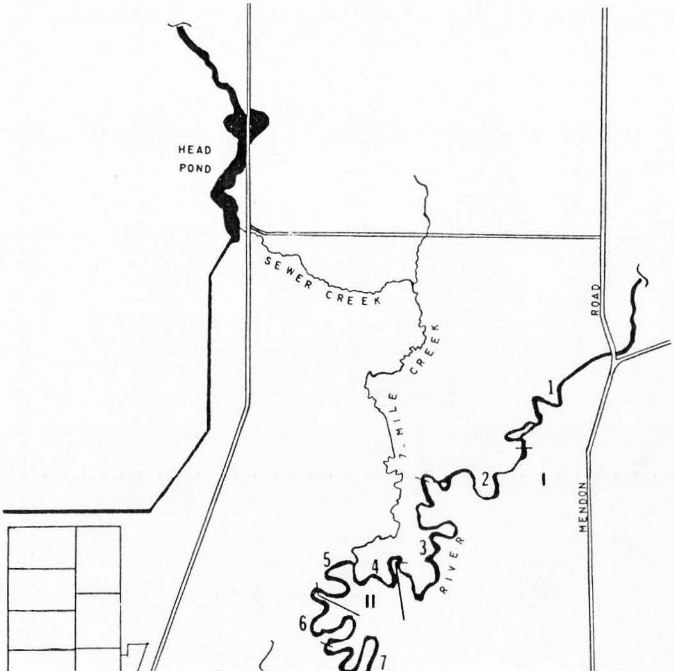

Figure 1. Map of Logan River study area showing collection stations and location of Logan City oxidation ponds. Matthews' stations are indicated by Roman numerals.

Table 1. Selected physical features of the study area. Unless indicated otherwise, measurements were made during late summer.

Section	Length (M)	Mean width (M)	% riffle 1970	% riffle 1971	% Bank cover 1970	% Bank cover 1971	Sinuosity index[a]	Gradient M/Km.	Mean midchannel depth (M)
1	765	7.83	20.91	24.84	46.9	46.2	1.448[b]	2.732	4.21[c]
2	834	7.33	14.14	10.79	48.6	67.7	1.935	1.103	3.89
3	1170	7.24	23.50	14.53	49.0	75.0	3.000	.897	3.82
4	453	5.44	12.14	4.42	49.1	78.3	2.384	.573	4.38
5	402	9.18	19.65	10.72	28.5	81.5	2.323	.398	4.38
6	653	8.68	1.53	0.00	34.0	92.2	2.839	.404	8.11
7	1095	9.26	0.00	0.00	37.3	83.3	3.421	.255	6.04
8	941	12.12	0.00	0.00	43.4	88.1	4.705	.244	6.13
7-Mile	390	3.60	0.00	0.00	36.7	36.7	1.646	2.30	.75

[a]Sinuosity index = $\frac{\text{Stream length}}{\text{Valley length}}$ (Morisawa, 1968, p. 138).

[b]Sinuosity in section 1 in 1971 was 1.438 due to rechannelization caused by flooding during spring runoff.

[c]Measured at 8 meter intervals - February 1972.

Table 2. Pertinent chemical and physical data of the study area.

Station	Measurement	Range	Mean	Source
Logan River (1970-1971)				
Above 7-Mile	Turbidity	47-98	88	-
	E.C.[e]	310-1250	610	-
	D.O. ppm[f]	7.9-11.5	10.0	-
	B.O.D. ppm	1.02-2.98	1.98	-
Below 7-Mile	Turbidity	42-99	87	-
	Conductivity	310-2100	560	-
	D.O. ppm[f]	8.6-11.8	10.5	-
	B.O.D. ppm	1.39-5.10	2.90	-
7-Mile	D.O. ppm[f]	7.7-9.32	8.6	-
	B.O.D.	.31-3.84	2.38	
(1965-66)	B.O.D.	1.60-34.00	15.00	Matthews (1966)
Mendon Bridge (1965)	Ca ppm	34-75	55	U.S.B.R.[d] (1965)
	Mg ppm	13-26	20	U.S.B.R. (1965)
	Na ppm	3-8	5	U.S.B.R. (1965)
	K ppm	0.8-2.3	1.2	U.S.B.R. (1965)
	CO_3 ppm	0.4-1.1	0.7	U.S.B.R. (1965)
	HCO_3 ppm	160-336	240	U.S.B.R. (1965)
	Cl ppm	3-9	6	U.S.B.R. (1965)
	SO_4 ppm	10-35	21	U.S.B.R. (1965)
	TDS[b] ppm	180-336	235	U.S.B.R. (1965)
	E.C.[e]	292-540	410	U.S.B.R. (1965)
	pH	7.4-8.5	8.1	U.S.B.R. (1965)
Mendon Bridge (1956-57)	NO_3 ppm[a]	0.0-4.9	-	McConnell (1958)
	PO_4 ppm	0.0-0.8	-	McConnell (1958)
	K ppm	0.1-2.0	-	McConnell (1958)
	Cl ppm	6.0-8.0	-	McConnell (1958)
	SO_4 ppm	12-15	-	McConnell (1958)
	Ca ppm	28-58	-	McConnell (1958)
	Mg ppm	24-28	-	McConnell (1958)
	Na ppm	5-25	-	McConnell (1958)
	HCO_3 ppm	240-264	-	McConnell (1958)
	TDS ppm[b]	185-230	-	McConnell (1958)
	Turbidity[c]	2-12	-	McConnell (1958)

[a] ppm equals parts per million (mg/L)
[b] TDS equals total dissolved solids
[c] Data reported in terms of SiO_2 standards (ppm)
[d] United States Bureau of Reclamation, Logan, Utah
[e] Electrical conductivity of the water in microhms
[f] Dissolved oxygen concentration of the surface water

The river flow is augumented by inflows from 7-Mile Creek and several minor irrigation returns. The annual discharge pattern of the river as monitored at the Mendon Bridge by the United States Geological Survey is typical of small rivers in the intermountain region with minimum flows during late summer caused by irrigation withdrawals and maximum flows during May and June due to snow melt on the watershed. During August of 1970 the entire river was diverted above Mendon Bridge for irrigation purposes resulting in a rapid drop in water level in the study area. The only water flowing in the river at this time was from 7-Mile Creek and limited irrigation returns. This minimal flow in 1970 was followed in the spring of 1971 by the highest flows ever recorded (53.5 m^3/sec., May 16, 1971) at this gauging station. The river was only partially diverted during 1971 and flows remained relatively high throughout the summer. Mean temperatures and flow rates during the study are shown in Figure 2.

The annual discharge pattern of 7-Mile Creek during the study was similar to that described by Matthews (1966). Minimum flows occurred during late summer (August) with higher flow rates during the fall and winter months. During the high runoff in May and June of 1971 the lower end of 7-Mile Creek lost its integrity as a distinct water course when the Logan River overflowed its banks and flooded the lower areas along the river. This condition existed for approximately four weeks.

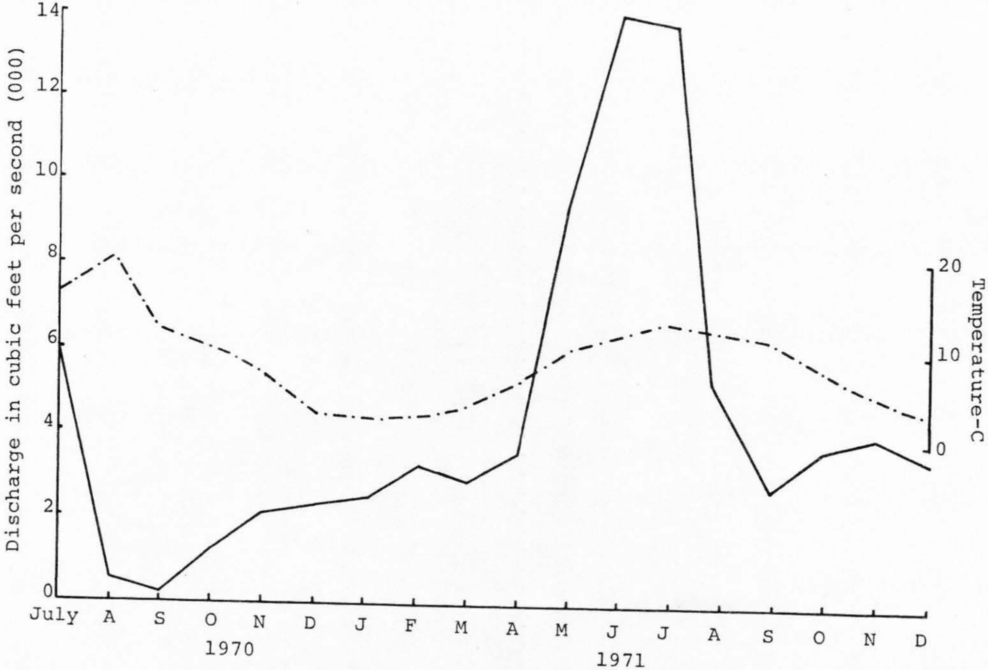

Figure 2. Mean monthly temperature and discharge pattern in the study area during 1970-72. Temperatures are indicated by dashed line.

Several aspects of the aquatic communities in the study area have been investigated. McConnell (1958) and Clark (1958) studied algal components of the river biota. Bangeter (1966) briefly surveyed the fish and invertebrate fauna of the river while more intensive investigations of these communities were conducted by Matthews and Neuhold (1967) and Erman (1968). Beers (1969) investigated the rates of benthic algal production and *Sphaerotilus* assimilation in the study area.

METHODS

Selection of River Sections

The study area was divided into nine sections: four sections above and below 7-Mile Creek and the lower 0.4 kilometers of 7-Mile Creek. Sections 1-2-3, 4-5, 6-7-8, and 7-Mile are essentially identical to Matthews (1966) sections I, II, III, and IV (Figure 1). Seven Mile Creek enters the river immediately between sections 4 and 5. The choice of the section boundaries other than those established by Matthews was based on the presence of physical characteristics of the river such as the end of specific riffles or pools.

Fish Collections

A checklist of fish species collected from April 1970 to January 1972 is shown in Table 3. The numbers and location of capture of all species collected during the study are given in Tables 4 and 5.

Fish collections were made during all seasons of the year with the most intensive collecting occurring during the summer months.

A small beach seine was used to a limited extent for collecting fish in the flooded areas during high water and in the quieter areas of the river at other times.

Table 3. Check list of fish collected in study area April 1970 - January 1972.[a]

Common name	Scientific name
Mountain whitefish	*Prosopium williamsoni* (Girad)
Carp	*Cyprinus carpio* Linnaeus
Utah sucker	*Catostomus ardens* Jorden and Gilbert
Brown trout	*Salmo trutto* Linnaeus
Rainbow trout	*Salmo gairdneri* Richardson
Cutthroat trout	*Salmo clarki* Richardson
Black bullhead	*Ictalurus melas* (Rafinesque)
Yellow perch	*Perca flavescens* (Mitchell)
Green sunfish	*Lepomis cyanellus* Rafinesque
Largemouth bass	*Micropterus salmoides* (Lacepede)
Black crappie	*Pomoxis nigromaculatus* (Lesueur)
Utah chub	*Gila atraria* (Girard)
Red shiner	*Notropis lutrensis* (Baird and Girard)
Brook trout	*Salvelinus fontinalis* (Mitchell)
Speckled dace	*Rhinichthys osculus* (Girard)
Arctic grayling	*Thymallus arcticus* (Pallas)
Mountain sucker	*Catostomus platyrhynchus* (Cope)
Gold fish	*Carassius auratus* (Linnaeus)
Mottled sculpin	*Cottus bairdi* Girard

[a]Common and scientific names used are those given in the American Fishery Society Special Publication No. 6, "A List of Common and Scientific Names of Fishes from the United States and Canada," 3rd. Ed., 1970.

Cylindrical wire fish traps as described by Kemmerer (1970) were used frequently in 7-Mile Creek during the study.

The best and consequently the most intensively utilized method of fish collection was electrofishing. This was accomplished with a single-boom shocker boat. Three 32-strand twisted copper wire cables were used as electrodes, one extending from the bow mounted boom and the other two from flexible connectors located opposite one another amidship. The front electrode extended approximately two meters into the water; side electrodes extended approximately 1.5 meters into the water. Electricity was supplied from a 2500 watt (230 volts), 180 cycle, 3-phase, alternating current, gasoline generator. All collections were made during daylight hours.

Shocked fish were placed in two live boxes aboard the boat. Fish were identified, weighed, measured, tagged or marked and scale samples were taken from below the origin of the dorsal fin. Fish were released in the same area in which they were captured. No anesthetic was used during the fish handling operation. Fish were weighed to the nearest gram using a pan balance. Total and standard length measurements were obtained for all fish on a conventional fish measuring board. Total length is the greatest length of a fish from its anterior most extremity to the end of the longest caudal fin ray. Standard length is the greatest length from the anterior most extremity to the base of the caudal fin rays.

Consecutively numbered and color coded vinyl plastic anchor tags (Dell, 1968) were used to tag all fish over 40 grams. Fish smaller than this were fin clipped for location identification. Fin clipping was used most extensively on the age 0 whitefish. The entire fin was removed which was sufficient to insure identification throughout the summer.

Fish movement

The extent of fish movement within the study area was estimated by examining the difference between the section and date of tagging and the section and the date of recapture. Movement patterns were also determined for 1-10, 11-20, 21-30 and over 30 days since previous recapture. A matrix of the numbers of fish recaptured and the location of recapture and previous location of capture was constructed for each time interval and species. From this the general movement patterns were identified. A hypothetical example of such a matrix is shown in Figure 3.

Those fish recaptured in the same section in which they were tagged would occur on the diagonal axis as indicated by the A's where A equals the number of fish recaptured. Any individuals above the diagonal would have moved down stream; any below would have moved up stream. In the example, six fish were recaptured in section 7 after having been previously captured in section 3; four were recaptured in section 5 after having been captured in section 6 and so on.

Location of capture	1	2	3	4	5	6	7	8
8								A
7			6				A	
6		2		3		A		
5					A	4	1	
4		1		A				
3			A		2			
2		A						
1	A							1

Location of previous capture

Figure 3. A hypothetical example of fish movement matrix.

White's (White, 1973) H value was used to analyze the relationship of location of recapture and previous capture location. It was derived from an information theory function and is the form

$$H = e^{\{\Sigma P_{ij} \ln P_{ij} - \frac{1}{2}\Sigma P_{i\cdot} \ln P_{i\cdot} - \frac{1}{2}\Sigma P_{\cdot j} \ln P_{\cdot j}\}}$$

where $P_{ij} = \frac{n_{ij}}{N}$, n_{ij} being the sum of recaptures in a given block and N is the total number of individuals in the given collection. $P_{i\cdot} = \frac{n_{i\cdot}}{N}$ where $n_{i\cdot}$ is the sum of recaptures from a given location and $P_{\cdot j} = \frac{n_{\cdot j}}{N}$ where $n_{\cdot j}$ is the sum of previous recaptures in a given location.

H measures the strength of the relationship between two categorical variables, in this case location of capture and location of previous capture. The lowest possible H in an 8 x 8 table would be 1/8 or .125. An H of .30 to .40 could be considered moderately good and an H of .60 to .70 or higher would be considered a strong relationship. Being independent of sample size, it has obvious advantages over the chi square analysis. For example, with a large sample size one could get a significant χ^2 value but not a high H. The opposite is also possible, i.e., a high H and a low χ^2 value. Its weakness lies in the fact that no method of estimating confidence intervals have as yet been established for H.

Age, growth and condition

Standard techniques were employed to determine age and growth relationships. Sigler (1953) and Tesch (1968) can be consulted for detailed methodology. Where possible, scale samples were collected from below the origin of the dorsal fin from all species with the exception of the carp. In this species opercular bones were used for age and growth determinations in the manner described by McConnell (1951). Carlanders third degree polynomial model (Lagler, 1956) or the direct proportion method was used to relate body length to scale or opercular size.

The coefficient of condition or condition factor (K) was computed using the equation described by Carlander (1969). This equation is $K = \frac{w \times 10^5}{L^3}$ where w is the weight in grams and L is the length in millimeters.

Instantaneous rate of growth, was computed as:

$$g = \frac{\log w_2 - \log w_1}{\Delta T} \quad \text{(Chapman, 1968)}$$

where w_1 and w_2 are estimated weights of fish at times t_1 and t_2.

Mortality was determined from catch curves as described by Ricker (1958). These curves were obtained by plotting the log of the numbers of individuals against age. A straight line was fitted to the descending right limb of the curve by the least squares method. The instantaneous rate of mortality i was determined by changing the sign of the slope of the regression line and multiplying by 2.3026. A table of exponential functions was used to obtain the annual rate of survival from the equation $s = e^{-i}$. The annual mortality rate, a, is equal to 1 - s.

Fish Production

Population estimates

Population estimates of the carp, brown trout, and whitefish were made using the Bailey modification of the Peterson method (Ricker, 1958):

$$N = \frac{M(C + 1)}{R + 1}$$

where,

N = estimate of the total number of fish in the population

M = total number of marked fish in the population

C = total catch of recaptures, and

R = number of recaptured fish.

Population estimates were based on electrofishing recaptures only.

A knowledge of when the fish were tagged allowed population estimates to be made during discrete time intervals. Since it took five to ten days to adequately sample the river above or below 7-Mile (the areas for which population estimates were made) the catch during this period was pooled to obtain population estimates. Recruitment to the catchable population was assumed to be negligible during the recovery periods.

Approximate 95 percent confidence intervals for N were obtained from tables presented by Ricker (1958) and Clopper and Pearson (1943) in the manner described by Ricker (1958).

After plotting individual estimates, a curve of total abundance N (of each species) against time was fitted by inspection taking into account confidence limits, sample sizes and movement patterns. Interim monthly estimates were based on this line.

The abundance of each year class was estimated from the proportion of the total catch each represented during any given month. A curve of relative abundance for each year class was fitted by inspection to these points. Monthly values taken from these curves were, in turn, projected to the total population estimates to obtain the monthly population estimates of each year class.

Monthly production estimates were calculated according to methods outlined by Ricker (1958). They were calculated as $P = g\overline{B}$ where g = instantaneous growth rate and

$\overline{B}$ = mean monthly biomass

Mean monthly biomass $\overline{B}$ represented the mean of biomass at the beginning and end of each month. Biomass at the beginning of each month was calculated as the product of numbers of fish at each age and mean weight of individual fish of that age. A modification of the computer program used by

Hunt (1966) was employed to carry out the mathematical calculations of production.

The exponential growth model of Ricker and Foerster (1948) was used to obtain production estimates of age 0 whitefish.

Gonad Production

Estimated gonadal weight losses due to spawning were calculated from pre and post spawning gonadal weight-total length linear regression lines. During pre and post spawning periods gonads were removed from selected individuals and weighed to the nearest gram. Gonad weights were plotted against total lengths and straight lines were fitted to the two sets of points by least square techniques. The algebraic difference between these lines (at the approximate mean length of spawning fish) was considered the average weight loss per individual due to shedding of gonadal products. From population estimates and known sex ratios the numbers of each sex present at spawning was estimated. Total gonadal production was considered the product of this number and the estimated individual weight loss due to shedding of gonadal products.

Fish Population Structure

Species diversity

The Shannon-Weaver index of general diversity D (Odum, 1971) was calculated for pooled collections for each location in both 1970 and 1971. It was calculated as:

$$D = -\Sigma p_i \log_e P_i$$

Where, $P_i = \frac{n_i}{N}$ when n_i is the number of individuals of species i and N is the total number of all individuals in the sample.

Cluster analysis

A cluster analysis of the fish collections were performed utilizing a computerized program described by Estabrook and Rogers (1966). This program was developed originally as a tool for the analysis of large amounts of taxonomic data. Its usefulness in this study was primarily in its ability to calculate similarity values based on objects (collections) which were described by characters (species) which were in turn divisible into character states (1,2,3,4) which represent numbers of each species in a collection. For a detailed description of the theory behind the program, Estabrook and Rogers (1966) and Wirth, Estabrook and Rogers (1966) should be consulted. Briefly, for each possible pair of objects (collections) in the study, a similarity value (C) is calculated based on the similarity of species and numbers of each species present.

To reduce the variability due to differences in effort expended in making the collections, catch per unit of effort for each species was used as the character value rather than actual catch. Fifteen minutes of electrofishing was arbitrarily chosen as the unit of effort.

In the present application, well ordered characters were used to describe similarities between states. All immediately adjacent states were assigned the similarity value of .500. States separated by one were assigned a value of .250. All others separated by more than one state were considered completely dissimilar and were assigned a similarity value of zero. This process of assigning between state similarity values in a ordered fashion should eliminate bias from the calculation of collection similarity values.

The program lists each object (collection) and its ten most similar objects in decreasing level of similarity. Each collection and its three most similar collections were used to describe the distribution and composition of the fish population in the study area.

Morphometric Measurements and Water Analysis

Measurements of riffles, bank cover, section length and width, and sinuosity were taken from a detailed scaled map of the study area drawn from aerial photographs and measurements and observations made in the field. Gradients were measured with a standard surveyor's level. Sinuosity was measured as stream length/valley length (Morisawa, 1968). The percentage of shore line covered by brush and tree branches actually entering the water at the time of measurement was considered bank cover. Mid channel depth measurements were made at approximately eight meter intervals over the entire study area with a Sportman's dial fathometer. Water temperatures were measured with pocket mercury thermometers or maximum-minimum recording thermometers at the Mendon Bridge, 7-Mile Creek and the lower end of the study area.

Water samples for 5-day biochemical oxygen demand (BOD) determinations were analyzed in accordance with American Public Health Association Standard Methods (1960). River discharge rates were obtained from U. S. Geological Survey flow records. Conductivity in microhms was measured with a portable Industrial Instruments Incorporated Model RB-3 conductivity meter.

RESULTS AND DISCUSSION

The Fish Population

The species composition of the fish population in the Logan River has changed considerably in the last half century. Interviews of several long time resident fishermen in Cache Valley indicate that prior to about 1940 chubs and suckers were the dominant fish species in the valley portion of the river. These most likely were the Utah chub, *Gila artraria*, and the Utah sucker, *Catastomous ardens*. Carp were apparently present in the river at least fifty years ago but did not become abundant until about 25-30 years ago at which time the suckers and chubs reportedly "vanished" from the lower portions of the river. The timing of this phenomenon (i.e., 25-30 years ago) was remarkably consistant among the individuals interviewed.

Prior to this time "natives" (probably cutthroat trout) and whitefish were seldom, if ever, caught or observed in the lower reaches of the river. There was however a slight inconsistency among those interviewed as to the abundance of whitefish in the river in past years.

Largemouth bass and bullheads have apparently been present in the Little Bear River marsh for at least 30 years. Their previous presence in the study area could not however be verified although it is probable that they were present in the lower portions of the river.

The change in species composition in the river was roughly coincidental with the onset of domestic sewage discharges into the river. Sewage was first discharged into the river about 40-45 years ago (personal communication, Mr. Frank Cowley, Logan, Utah).

The changes in the fish population resulting from this discharge would not necessarily have been rapid. More probably, the change was one of slow displacement of one or more species (chubs and suckers) by another (carp) as the habitat gradually changed with the continual input of organic wastes. This could explain the 10-15 year discrepancy between the onset of the sewage discharges and the first noticeable changes in the fish population.

Other factors which might have influenced the fish population in the lower river are changes in use patterns on the watershed, irrigation practices and an overall reduction in the quality of river habitat upstream from the study area.

The present fish population in the study area can best be described by examining the similarities of each collection made in each location with its three most similar collections as is shown in Figure 4. Each dot indicates one of the three most similar collections. For example, in section 2 (on the abcissa) there were 8 collections in section 1 that were very similar, 2 in section 2, 7 in section 3, 2 in section 4 and so on. Only two collections below 7-Mile Creek (entering between 4 and 5) were in the "three most similar" category.

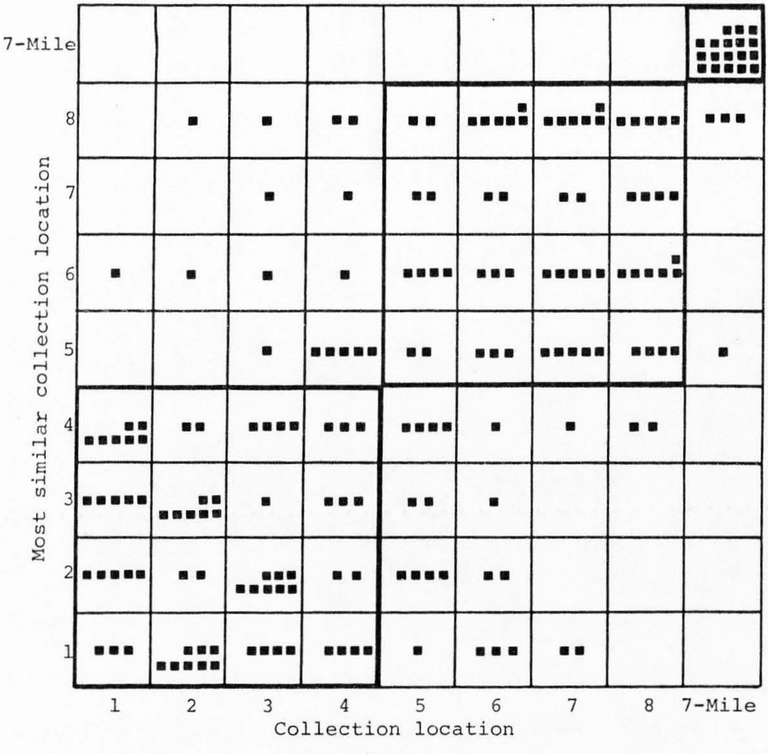

Figure 4. Groupings of similar fish collections based on similarity values. The position of each square represents one of the three most similar collection locations (on the ordinate) to each collection and its respective location on the abscissa. Three distinct groupings are shown within the heavy lines.

Three fairly distinct groupings can be seen in which abundance and species composition are similar. The general locations of these groupings correspond roughly to sections 1-4, 5-8 and 7-Mile Creek. From this it is evident that the species composition is quite distinct above and below 7-Mile Creek with an apparent transition (sections 4 and 5) between the two areas.

The population above 7-Mile Creek is characterized by whitefish and the trout with relatively few carp and suckers. Below 7-Mile this relationship is reversed with carp and suckers predominating and whitefish and trout occurring in low numbers (this was especially evident in 1970). This relationship reflects the differences in habitat in the two areas. Accordingly, the transition populations are apparent in the habitat transition zone.

The distinctness of the 7-Mile grouping is due to the consistantly large numbers of carp captured and the frequent presence of bullheads and green sunfish in the collections. The latter two species were seldom captured elsewhere in the study area. The predominance of these three species and the near absence of the trout in 7-Mile contribute to the dissimilarity of this creek from the rest of the study area.

Tables 4 and 5 show the distribution of fishes collected by stream sections during 1970 and 1971. There was no significant difference between the mean number of

Table 4. Number of fish collected by location in the study area during 1970.

Species	Section 1	2	3	4	5	6	7	8	7-Mile Cr.
Whitefish	220	175	224	104	100	38	9		12
Carp	141	128	208	64	71	43	110	100	123
Utah sucker	51	30	73	39	24	64	31	11	35
Brown trout	63	58	65	16	13	5	4		
Rainbow trout	1	2	3	3	1			1	1
Cutthroat trout		2	2	2	4	1	1		
Black bullhead	3		6	3	11	4	4	5	42
Yellow perch						1	5	2	
Green sunfish			1		2	3	1	5	9
Largemouth bass									1
Black crappie							2	1	
Utah chub	2								
Red shiner	3								
Brook trout									
Speckled dace		4							
Grayling									
Mountain sucker	1								1
Goldfish									
Mottled sculpin									

Table 5. Number of fish collected by location in the study area during 1971.

	Section								
Species	1	2	3	4	5	6	7	8	7-Mile Cr.
Whitefish	1234	583	664	200	203	181	117	68	131
Carp	268	86	143	52	81	53	90	103	282
Utah sucker	88	53	56	12	11	10	22	12	70
Brown trout	183	86	104	27	13	14	19	7	4
Rainbow trout	8	7	7	7	5	7	4	2	2
Cutthroat trout	3	3	2		6	3	1	1	1
Black bullhead	2		3			7	4	12	52
Yellow perch									
Green sunfish					1	1	1	1	21
Largemouth bass							1		2
Black crappie									
Utah chub	3	2	1	1			2		8
Red shiner	1								1
Brook trout	2								
Speckled dace									
Grayling	1		2						
Mountain sucker									
Goldfish								1	
Mottled sculpin									

species per station in 1970 and 1971 although replacement by different species was evident.

Seven-Mile Creek had a very distinctive population from which almost all other collections were dissimilar. Carp were the most abundant species in 7-Mile Creek followed in abundance by suckers, bullheads and strangely enough, young of the year whitefish.

Diversity indices based on pooled collections from each location for 1970 and 1971 are shown in Figure 5. Pooled values were believed to be more representative of the actual diversities within a given section than were diversity values based on individual collections which seldom included more than 5 or 6 different species. There was no significant difference in diversity (D) in 1970 and 1971 however in both years the greatest changes in diversity occurred in sections 7 and 8.

Harrel et al. (1967) postulated that an increase in fish species diversity with stream order (generally with decreasing gradient) was the result of an increase in available habitat and decrease in environmental fluctuations. This could in part account for the observed increase in diversity in the lower sections of the river in 1971. The mean volume of flow increased, more habitat was available and environmental extremes such as temperature were less than they were in 1970. Conversely, the low flows in 1970 would have reduced available habitat and extremes in

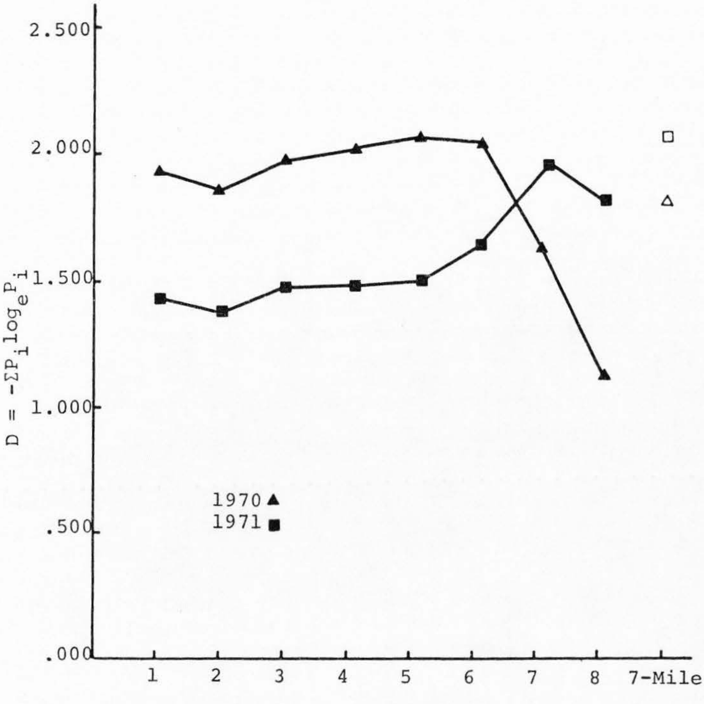

Figure 5. Diversity values based on pooled collections from each section during 1970-1972. 7-Mile Creek values are indicated with open symbols.

environmental conditions would have been more likely to occur. Because of the physical nature of the upper sections of the study area, extremes in flow would not have had as great an effect here as in the downstream sections.

Although there was no significant difference in the mean annual diversity values during the study, it is evident that in sections one through six, differences did exist during the two years. Why diversity was consistantly higher in these sections during a low water year is difficult to explain. It is conceivable that because the fish were more concentrated during low water the probability of encountering additional species would have been higher. There was however no significant difference in the number of species collected in 1970 and 1971. This would seem to suggest that diversity was perhaps dependent on sample size.

Theoretically, D, should be independent of sample size (Odum, 1971). It appears that the difference observed was a function of the relative abundance of certain species in the collections. The total number of the rarer species collected was about the same in both years. It was the great increase in the more common species (primarily white-fish) in 1971 that caused the reduced diversity value in this year. In other words, the rarer species made a much smaller contribution to the diversity value.

Species diversity values for all nine sections of the study area in 1970 and 1971 are compared with diversity values in other aquatic communities in Table 6. Diversity values for the Logan River were in the range generally associated with more rigorous or very uniform environments such as are found in polluted or physically altered habitats. The development of cattle and pig feed lots, channalization and indiscriminate dumping of debris in and along the river above the study area cannot be dismissed as possible causes of the low diversity values recorded in the study area.

In an attempt to determine what physical variables effected species diversity in the study area, several combinations of measured variables were regressed against diversity in each section for 1970 and 1971 (Tables 7 and 9). Simple correlations between the variables were also computed to determine what variables correlated best with species diversity in each year (Tables 8 and 10).

Although the small sample size ($N = 9$) makes a rigid interpretation of the results difficult, an equation including percent riffle, percent bank cover, gradient and interactions between percent riffle and bank cover and percent riffle and sinuosity resulted in a fair degree of precision. The best equation is (see Table 7 for definition of symbols):

$$s = 2.4776 - .03017A - .03754B - .46468D + .00296AB - .02482AC$$

The coefficient of determination for this equation is 0.898, significant at 90 percent, with a coefficient of variation

Table 6. Fish species diversity values for various aquatic communities.

Diversity values		Community Description	Source
(1970)	(1971)	Logan River	
1.901	1.430	Section 1	-
1.811	1.397	Section 2	-
1.940	1.480	Section 3	-
1.953	1.481	Section 4	-
2.036	1.500	Section 5	-
2.023	1.617	Section 6	-
1.649	1.955	Section 7	-
1.444	1.846	Section 8	-
1.829	2.073	7-Mile Creek	-
1.51-3.00 (mean 2.26)		10 stations Skunk River, Iowa	Laser et al., 1968
2.16		1 station at sewage treatment plant outfall Skunk River	
1.76-2.97 (mean 2.40)		9 stations Little Patuxent River 1958	Chu-Fa Tsai, 1970
1.11-2.85 (mean 2.21)		9 stations Little Patuxent River 1967 following deterioration of water quality	
.99-1.88 (mean 1.54)		4 stations Swan Falls Reservoir	Sigler et al., 1972
2.02-2.81 (mean 2.52)		6 stations below Swan Falls Dam Snake River, Idaho	

Table 7. Regression of selected variables against species diversity for 1970 (N = 9).

(A) Percent Riffle
(B) Percent Bank Cover
(C) Sinuosity
(D) Gradient, m/km

$$S = b_0 + b_1A + b_2B + b_3D + b_4AB + b_5AC$$

Variables	Error d.f.	Coefficient of determination	f-value[a]	Mean square error	C.V. (%)[b]
A,B,D,AB,AC	3	.898	5.333 (.900)	.0099	7.94
B,D,AB,AC	4	.737	2.805 (.750)	.0193	11.05
B,AB,AC	5	.493	1.625 (.500)	.0297	13.73
B,AB	6	.482	2.799 (.750)	.0253	12.69
AB	7	.217	1.941 (.750)	.0328	14.44

[a]level of significance in parenthesis

[b]Coefficient of variation = $\frac{(\text{Residual mean square})^{\frac{1}{2}}}{\text{Mean diversity}}$

Table 8. Correlation matrix (R x 100) between parameters used for development of regression equation for 1970, (N = 9). The level of significance of each coefficient is indicated in parenthesis for H_o: $\rho = 0$ (Snedecor, 1971, p. 184).

(S) Species Diversity
(A) Percent riffle
(B) Percent Bank Cover
(D) Gradient, m/km
(AB) Percent riffle x Percent gradient
(AC) Percent riffle x sinuosity

	A	B	C	D	AB	AC
S	52(80)	-15(50)	-74(95)	24(50)	46(70)	50(80)
A		35(60)	-43(70)	61(90)	96(99)	93(99)
B			- 4(50)	49(80)	57(80)	32(50)
C				-52(80)	-42(70)	-25(50)
D					69(95)	35(60)
AB						90(99)

Table 9. Regression of selected variables against species diversity for 1971 (N = 9).

(A) Percent riffle
(B) Percent bank cover
(C) Sinuosity
(D) Gradient, m/km

$$A = b_0 + b_1A + b_2B + b_3D + b_4AB + b_5AC$$

Variables	Error d.f.	Coefficient of determination	f-value[a]	Mean square error	C.V. (%)[b]
A,B,D,AB,AC	3	.942	9.778 (.950)	.0047	6.00
A,B,D,AB	4	.897	8.733 (.950)	.0062	6.92
A,D,AB	5	.820	7.605 (.950)	.0087	8.19
A,AB	6	.616	4.824 (.900)	.0154	10.92
AB	7	.610	10.991 (.975)	.0135	10.19

[a] Level of significance enclosed in parenthesis.

[b] Coefficient of determination = $\frac{(\text{Residual mean square})^{1/2}}{\text{Mean diversity}}$

Table 10. Correlation matrix (R x 100) between parameters used for development of regression equation for 1971 (N = 9). The level of significance of each coefficient is indicated within parenthesis for H_o: $\rho = 0$ (Snedecor, 1971, p. 184).

(S) Species diversity
(A) Percent riffle
(B) Percent Bank Cover
(C) Sinuosity index
(D) Gradient, m/km
(AB) Percent riffle x percent gradient
(AC) Percent riffle x sinuosity

	A	B	C	D	AB	AC
S	-71(95)	-13(50)	33(60)	-58(80)	-78(95)	-73(95)
A		-39(70)	-51(80)	89(99)	94(99)	91(99)
B			72(95)	-47(80)	-25(50)	-23(50)
C				-51(80)	-45(70)	-37(60)
D					71(95)	67(95)
AB						98(99)

of 7.8 percent. The sinuosity index, which correlated well with diversity, did not in previous attempts to develop prediction equations, increase their precision.

The midchannel depth was also considered but it was found to add little to the precision of the equations. This is contrary to that reported by Sheldon (1968) who found fish species diversity to be dependent solely on depth alone in Owego Creek, New York. He did concede however that other structural features of the habitat such as roots and logs (Bank Cover!) could significantly influence diversity. A number of studies including those of Kuehne (1962), Larimore and Smith (1963), and others support the importance of habitat structural diversity in determining the diversity among stream fishes.

Regressing the same physical variables against diversity in 1971 resulted in somewhat greater precision of the best prediction equation (Table 9). That equation was:

$$s = 1.67712 + .109972A - .00302B - .57047D - .00185AB + .01158AC$$

with a coefficient of determination of .942, significant at 95 percent with a coefficient of variation of 6.0 percent. In both 1970 and 1971 a measure of gradient and an interaction term between percent riffle and percent bank cover accounted for the greatest portion of the variability in diversity.

Because of its strictly numerical nature, the species diversity index D does not depict the functional role of the species in a fish population. This is particularly evident where a distinct change in species composition occurs in a relatively short distance. For instance, one could have identical diversity indices with entirely different species present. Such a situation would not reflect the suitability of the environment for a particular species.

With this in mind, a measure of the "trophic condition" (Brinkhurst et al., 1968) of the fish population in each section of the study area was calculated. This index was originally used to describe the pollutional status of portions of the St. Lawrence Great Lakes utilizing various species of chironomids as indicator organisms. It is a means of simply describing, in a quantitative manner, a very basic functional response of an organism to its environment. Inasmuch as trophic refers to feeding, the name given this index by Brinkhurst is somewhat misleading. For simplicity however, it will be maintained during this discussion. To calculate this index, the species collected were divided into three categories corresponding to their ability to tolerate a degraded, polluted or highly eutrophic environment (Table 11). In the majority of cases this posed no serious problems as the environmental requirements of most fish are fairly well known. In the case of a few of the rarer forms in the river such as the speckled dace and mountain sucker, their categorization was primarily a reflection of the type of habitat in which they were found.

Table 11. Classification of fish species into "trophic" categories reflecting their relative tolerance to degraded or polluted habitat conditions.

n_0 Intolerant	n_1 Moderately tolerant or facultative	n_2 Tolerant
Grayling	Speckled dace	Utah chub
Rainbow trout	Largemouth bass	Utah sucker
Brown trout	Crappie	Red shiner
Cutthroat trout	Yellow perch	Green sunfish
Brook trout	Mountain sucker	Black bullhead
Mountain whitefish		Carp
Mottled sculpin		Goldfish

The values 0, 1 and 2 were assigned to the three categories to correspond to their increasing ability to withstand degraded conditions. The "trophic condition" index was calculated using the formula

$$T.C. = \frac{\Sigma n_1 + 2\Sigma n_2}{\Sigma n_1 + \Sigma n_2 + \Sigma n_3}$$

where n_1, n_2 and n_3 represent the number of individuals in a given taxa which has been classed respectively as intolerant, facultative or tolerant. The theoretical maximum and minimum values for this equation are 2.0 and 0.0 respectively. A high value would indicate the presence of species tolerant of degraded habitat conditions. Low values would indicate the presence of predominately sensitive species. It would be unlikely to obtain a value of 0.0 in the Logan River because of the presence of cosmopolitan species such as the carp and Utah suckers which are found in all sections of the study area. The range of values obtained in both 1970 and 1971 illustrate the down-stream longitudinal differences in the "trophic status" of the fish in the study area (Figure 6). It is probable that the consistently higher values in 1970 were a reflection of the main physical differences in the river in these two years, i.e., flow rates and probably temperature. In 1970 habitat conditions were more extreme throughout the study area due to low water levels. As a result, intolerant species were less abundant causing the trophic condition to

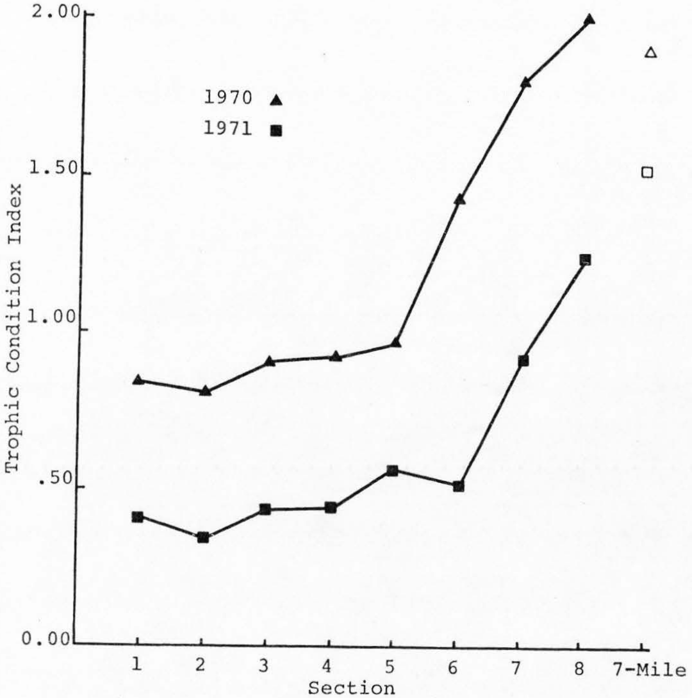

Figure 6. Trophic Condition Index values in the study area during 1970 and 1971.

increase. In the higher water of 1971 the habitat was apparently improved resulting in lowered index values. The lower sections of the river and 7-Mile Creek reflected degraded habitat conditions based on the types of fish present. Since sewage is no longer discharged into the river this would suggest one of two things; the river is still in the process of recovering from the previous organic pollution, or the physical habitat delimits the abundance and distribution of the fish species present in the study area. Based on water quality data and the large differences observed in the index in the two years of the study, the latter appears to be the case.

In an effort to gain some insight of the physical factors influencing "trophic condition" in the river, four selected variables were regressed against the index value in each section of the study area during 1970 and 1971 (Tables 12 and 14). In both years percent riffle emerged as the most important variable in predicting "trophic condition." In 1970, the addition of a measure of sinuosity improved the equation somewhat. The best equation for this year was:

$$T.C. = 1.391 + 0.108(B) - 0.038(C)$$

where B is a measure of stream sinuosity and C a measure of riffle area. The coefficient of determination for this equation was .828, significant at 99.5 percent with a coefficient of variation of 17.8 percent.

Table 12. Regression of selected variables against trophic condition factor for 1970 (N = 9).

(A) Bank cover (%)
(B) Sinuosity
(C) % riffle
(D) Gradient, m/km

$$T.C. = b_0 + b_1A + b_2B + b_3C + b_4D$$

Variables	Error d.f.	Coefficient of determination	f-value[a]	Mean square error	C.V. (%)[b]
A,B,C,D	4	.841	5.301 (.900)	.0731	21.01
A,B,C	5	.839	8.745 (.975)	.0592	18.96
B,C	6	.828	14.603 (.995)	.0527	17.87
C	7	.787	25.732 (.995)	.0561	18.46

[a]Level of significance enclosed with parenthesis.

[b]Coefficient of variation = $\frac{(\text{residual mean square})^{1/2}}{\text{mean of dependent variable}}$

Table 13. Correlation matrix (R x 100) between parameters used for development of regression equation for 1970 (N = 9). The level of significance of each coefficient is indicated in parenthesis for H_o: $\rho = 0$ (Snedecor, 1971, p. 184).

(T.C.) Trophic condition index
(A) Bank cover, %
(B) Sinuosity
(C) % riffle
(D) Gradient, m/km

	A	B	C	D
TC	-4(50)	36(60)	49(80)	-38(70)
A		-44(70)	-53(80)	56(80)
B			62(90)	-89(99)
C				-62(90)

Table 14. Regression of selected variables against trophic condition factor for 1971 (N = 9).

(A) Bank cover, %
(B) Sinuosity
(C) % riffle
(D) Gradient, m/km

$$T.C. = b_0 + b_1A + b_2B + b_3C + b_4D$$

Variables	Error d.f.	Coefficient of determination	f-value[a]	Mean square error	C.V. (%)[b]
A,B,C,D	4	.914	11.060 (.975)	.0304	24.75
A,B,C	5	.897	14.551 (.995)	.0292	24.21
A,C	6	.679	6.386 (.950)	.0755	38.91
C	7	.389	4.448 (.900)	.1234	49.79

[a]Level of significance enclosed in parenthesis

[b]Coefficient of variation = $\frac{(\text{residual mean square})^{1/2}}{\text{mean of dependent variable}}$

Although gradient correlated moderately well with trophic condition (Table 13), it did not contribute greatly to the precision of the equation. Its effect was probably included in the effect of sinuosity and to a lesser extent, percent riffle, both of which have been shown to be related mathematically to velocity (Hynes, 1970).

In 1970 a combination of variables including bank cover (A), sinuosity (B) and percent riffle (C) produced the best prediction equation (Table 14). This equation was

$$T.C. = 1.807 - 0.023A + 0.306B - 0.032C$$

The coefficient of determination for this equation was .897, significant at 97.5 percent with a coefficient of variation of 24 percent. During 1971 bank cover was well correlated with trophic condition (Table 15) implying that the more bank cover present the higher the "trophic condition" or the poorer the overall habitat. This is somewhat misleading. More bank cover was present during 1971 because of the higher water, particularly in the lower sections of the river where thick brush covered most of the bank. Its high correlation with "trophic condition" is probably more a result of its coincidental distribution in the study area than a reflection of its relationship to "trophic condition." In 1970 bank cover was poorly correlated with trophic condition. It is suspected that the inclusion of a measure of bottom type or mean section velocity or both would have

Table 15. Correlation matrix (R x 100) between parameters used for development of regression equation for 1971 (N = 9). The level of significance of each coefficient is indicated in parenthesis for H_o: $\rho = 0$ (Snedecor 1971, p. 184).

(TC) Trophic condition index
(A) Bank cover, %
(B) Sinuosity
(C) % riffle
(D) Gradient, m/km

	A	B	C	D
TC	73(95)	-40(70)	-49(80)	-25(50)
A		-52(80)	-53(80)	31(50)
B			90(99)	-62(90)
C				-52(80)

added as much or perhaps more to the predictive power of the regression equation.

Fish Movement

The estimations of the extent of fish movement in the study area were based solely on information obtained from individually marked recaptured fish.

Whitefish

The movements of recaptured whitefish in the Logan River during the study are shown in Figure 7. Movements during the summer of 1970 were almost exclusively upstream. This appeared to be in response to the rapidly dropping water level at this time caused by the diversion of the river above the Mendon Bridge for irrigation purposes. Many fish apparently managed to get above this dam before the river was completely diverted. Over a thousand whitefish were observed immediately above the dam in late August. The majority of whitefish present in the study area at this time were age II and younger fish. Upon removal of the dam in early September, flows were increased from 14 cfs to 122 cfs and the study area was rapidly repopulated with whitefish of all represented age classes.

Bridges and Neuhold (1966) observed that upstream movement of whitefish in the canyon portion of the Logan River reached a peak in May with downstream movement peaking in November.

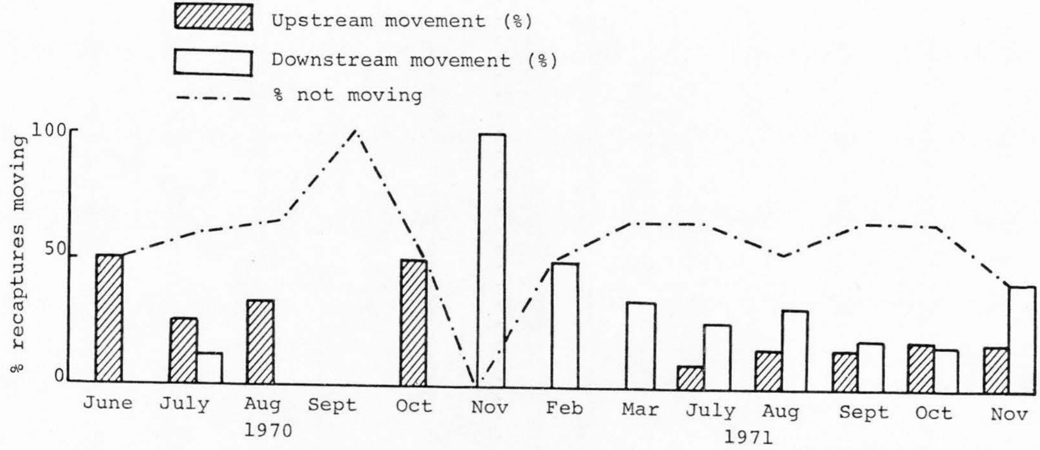

Figure 7. Movement patterns of recaptured Mountain Whitefish in the Logan River during 1970 and 1971.

A tendency toward downstream movement during the winter and early spring of 1971 was evident in the study area. Record flows in the study area during April, May and June made sampling hazardous so movement data are not available for this period however a slight downstream movement was evident in a small portion of the whitefish population during July, August and September. Matthews (1966) observed a similar downstream movement of whitefish in the study area during the winter and spring. He attributed this to increasing flows and the resulting improvement in water quality.

A direct comparison with Matthews' whitefish movement data is possible. By pooling recaptures from sections 1, 2 and 3; 4 and 5; and 6, 7 and 8 they become comparable to collections from his stations I, II and III. (His station III was actually somewhat longer than stations 6, 7 and 8 in the present study.) By examining the relationship of location recaptured to location of previous capture using White's H, it is possible to gain some insight into the strength of the relationship before and after the abatement of the sewage discharge. The comparison made here is for all recaptures and does not consider specific seasonal trends. It does reflect however the overall extent of movement within the populations during the two studies. Matthews' data and those of the present study are shown in Table 16. The lowest H value possible in a 3 x 3 table

Table 16. Whitefish collections in the study area in 1965 and 1970-1971 showing recapture location and number recaptured. 1965-1966 data from Matthews (1966).

1965-1966

Recapture location	I	II	III
III	3	3	3
II	13	22	3
I	108	11	4

Location of previous capture (columns)

N = 170
H = .6528

1970-1971

Recapture location	1-2-3	4-5	6-7-8
6-7-8	16	10	9
4-5	13	15	9
1-2-3	244	8	7

Location of previous capture (columns)

N = 331
H = .6171

would be 1/3 or .3333. The values of .5628 and .6171 would indicate a moderately strong relationship between location of previous recapture and recapture location during both studies with a slightly stronger relationship between the variables during 1970-1971. Because confidence intervals have not yet been developed for this statistic, differences are difficult to interpret. In any respect, the small differences observed suggest that the degree of whitefish movement is essentially the same now as it was prior to the pollution abatement and is very probably a reflection of natural seasonal movement patterns apparently unrelated to the level of pollution.

In testing the hypothesis that the variables are independent, a chi square value of 116.4 was obtained for the 1970-1971 data indicating that a significant relationship (significant at 95 percent level of confidence) existed between the recapture location and the location of previous capture. Although a significant chi square value (60.23) was obtained for Matthews' data the considerably higher value obtained in 1970-1971 suggests that the relationship between the variables was stronger in 1970-1971 than in the previous study.

A test of independence between year and movement was made using a 2 x 3 contingency chi square test. The percent of movement in Matthews' and the present study, and the result of the contingency table analysis are shown in Table 17.

Table 17. Percent of movement of recaptured whitefish during 1965-1966 and 1970-1971. Chi square value is .67, tabular $\chi^2_{(2,.05)} = 7.38$.

Year	Direction of Movement		
	Upstream	None	Downstream
1965-1966	10.6	78.2	11.2
1970-1971	7.3	80.9	11.8

Although slight changes in the degree of movement were evident, overall movements were not significantly different during the two studies.

Because any given section of the river was generally sampled biweekly throughout the summer months, an attempt was made to discern any immediate effects of handling and tagging on fish movement. Recaptures were grouped according to days since previous capture in the following manner: 1-10, 11-20, 21-30, over 30 days and all collections combined (Table 18). The strength of the relationship of whitefish recapture location to location of previous capture during the first ten days following recapture ($H = .4058$) was less than either of the two succeeding ten day intervals reflecting the initial downstream displacement following capture. The H values did not drop below the first ten day value until the fish had been at large for at least 30 days after which seasonal movements probably weakened the relationship with a resulting drop in H.

This suggests that the capture and tagging procedure had a limited traumatic affect on the fish producing a downstream movement with the current. After 10 or 20 days however, the fish generally appear to have moved back to their original capture location. This same pattern would have been evident if the fish which moved downstream initially continued their movement out of the study area or died, leaving only those that did not move to be recaptured

Table 18. Movement patterns of recaptured tagged whitefish.

Days since previous capture	Total number	% Recaptures moving Upstream	None	Downstream	H
1-10	68	9.6	53.3	36.9	.4058
11-20	47	16.4	68.3	14.3	.5043
21-30	58	16.4	61.8	21.6	.4216
Over 30	175	14.7	59.9	25.4	.3615
All collections	348	14.9	61.9	23.2	.3323

at a later date. Unfortunately very few fish were recaptured more than twice so this problem was never fully resolved.

Although fish were collected on downstream "swings" through each section and the tagged fish released in the same area in which they were captured, the overall downstream movement during the collection procedure may have influenced the recapture results by favoring the collection of downstream migrants over upstream migrants. Any fish recaptured on the same day that it was previously captured was not counted as a recapture and was immediately returned to the river in the location where it was recaptured.

All whitefish recaptures made during the study are included in Figure 8. In the first five sections of the study area the location of recapture of a given fish is strongly dependent on the location at which it was previously captured. In sections 6, 7 and 8 this relationship was not nearly as strong. The physical nature of the river here is quite homogenous and potential barriers to extensive or even random movements such as fast currents, riffles, or log jams were not present. The fish here are readily able to move between sections and in fact may of necessity be forced to move between sections in search of food. Several studies have shown that mountain whitefish are generally located in good pool areas that have an abundance of benthic fauna (Fleener, 1951; Sigler, 1951b; Godfrey, 1955). The lower

Location of recapture								
8	1	2			1		2	
7	1		5	2	3	2	1	2
6	2	1	4	2	2	1	1	
5	2		5	2	15	3	1	
4		2	4	11	3	3	2	
3	11	9	43	5	1			1
2	16	34	12	1			2	1
1	110	6	4	1		1	1	1
	1	2	3	4	5	6	7	8

Location of previous capture

Figure 8. Numbers and location of all whitefish recaptures made in the study area during 1970-1971.

sections of the study area do not meet these criteria. Erman (1968) found a progressive downstream decrease in number and volume of invertebrates in the study area and concluded that this was a function of decreased current velocity and substrate changes.

The concept of a home range related to distinct physical characteristics of the river should also be considered as a factor limiting movement in the upper reaches of the study area. Gerking (1950, 1953), in a detailed study of fish movements in Richland Creek, Indiana found that several species of centrarchids and one catastomid, the hog sucker, had definite home ranges from which even high water did not dislodge them. He also found that, in general, riffles were respected as boundaries to home ranges. Thus in the upper sections of the study area movements would be less likely to occur due to the numerous distinct riffles and pools present in this area.

Carp

Seasonal movement patterns of recaptured carp in the Logan River during 1970 and 1971 are shown in Figure 9.

Carp movements during July and August of 1970 appeared to be related to size and flow rates. The mean weight of upstream migrants during this period was 605 grams. Downstream migrants had a mean weight of 793 grams. Recaptured carp not moving during this period had a mean weight of 1198 grams. It appears that the smaller carp moved up into

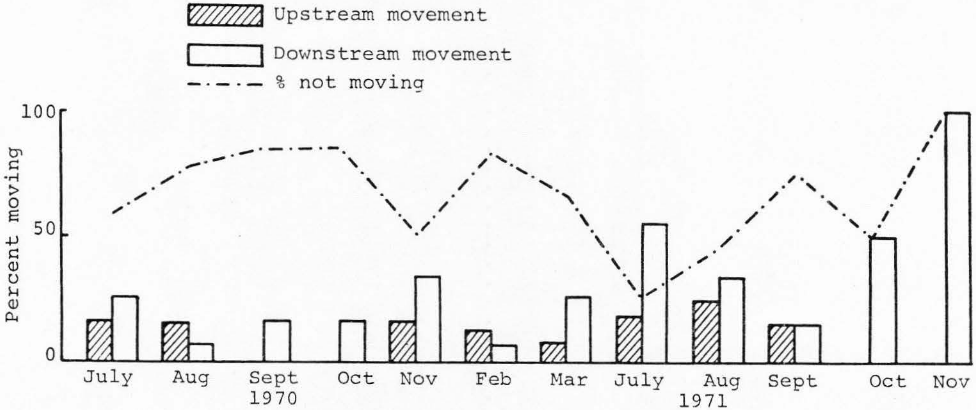

Figure 9. Movement patterns of recaptured carp in the Logan River during 1970-1971.

the study area as flow rates decreased following the spring runoff. It is conceivable that they were displaced downstream with the high water in May and June and moved back into the area as flow rates declined. During the low water period of 1971 the differences in weights of migrant and non migrant carp were not as great. In August and September the mean weights of downstream migrants was 1000 grams; upstream migrants had a mean weight of 1220 grams. Apparent nonmigrants had a mean weight of 1207 grams. The downstream movement (presumably out of the study area) of the smaller fish and upstream movement of the larger would account for the observed increase in mean individual weight of the fish during the fall of 1971.

Carp fry and fingerlings were seldom encountered in the study area suggesting that spawning and/or survival was limited in this portion of the Logan River. Carp fry were extremely abundant however in the Little Bear River Marsh, into which the Logan River flows, indicating the availability of suitable spawning habitat. Some of the downstream movement of carp in the spring could probably be attributed to a spawning migration into the marsh. A limited amount of downstream movement was evident in March 1971, prior to the onset of the spring runoff. In both 1970 and 1971 there was an evident downstream movement during the fall months.

The movement patterns of recaptured carp following their release are shown in Table 19. As was observed in the

Table 19. Movement pattern of recaptured carp following release.

Days since previous capture	Total Number	% recaptures moving Upstream	None	Downstream	H
1-10	14	0	42.8	57.2	.5672
11-20	12	25.0	50.0	25.0	.5801
21-30	31	6.4	80.8	12.8	.6620
Over 30	116	11.2	19.2	19.6	.4058
All collections[a] 1970-1971	172	10.4	68.2	21.4	.3783

[a]Total does not include fish moving in and out of 7-Mile Creek.

whitefish, an initial downstream movement was evident in the first 10 days following release. The relatively high percentage of downstream migrants in the first 10 day interval following capture again probably reflects a response to the handling and collection procedure. The strength of the relationship between location of previous capture and recapture location as indicated by H is moderately high in the first three intervals. The probable influence of seasonal movements is reflected in the lower H values recorded for periods over 30 days and all collections combined.

Figure 10 shows the distribution of all carp recaptures in the study area during 1970 and 1971. The grouping of recaptures reflects the relative distribution and overall movement pattern of carp in the study area.

Although carp were very abundant in 7-Mile Creek they were not recaptured there in great numbers. This was in part due to the short stretch of 7-Mile routinely sampled and the apparent exchange of fish between it and the Logan River. Although an equal number of recaptures had moved in and out of 7-Mile Creek, it is likely that the large number of fish tagged (405) in 7-Mile Creek moved upstream out of the collection area resulting in the relatively low recapture rate in this section.

When examining carp movement in the river it is of interest to consider two individual fish encountered during

Location of recapture									
7-Mile	4	1	3	1			2	1	6
8	1	1	1	1			2	5	3
7		1	1		2	1	4		
6		1	1	1	2	3	2	1	1
5			2	4	4		1		4
4		1	2	10			1		1
3	2	2	30	2					2
2	8	24	2	2					
1	37	3	2		2				1
	1	2	3	4	5	6	7	8	7-Mile

Location of previous capture

Figure 10. Numbers and location of all carp recaptures made in the Logan River during 1970-1971

the study. On August 31, 1970 a carp was collected in section 7 which had been tagged on July 9, 1964 by the Utah Division of Natural Resources just south of the Valley View Highway bridge. The distance between the two points is approximately 8 kilometers.

In October 1971, a dart tagged carp was observed in a marshy area of a spring run tributary to the Little Bear River near the town of Wellsville, Utah. This fish apparently moved down the Logan River to its confluence with the Little Bear and from there up the Little Bear to the spring run, a total distance of approximately 18 kilometers. An unsuccessful attempt was made to capture this fish by electrofishing the entire spring run in which it was observed. Funk (1955) referred to movement of the type exhibited by this fish as complex (down one stream and up the other) and found a small percentage of carp (7.8%) in Missouri streams making this type of movement. He also concluded that carp adapt their movements to the physical conditions of the habitat and that they were mostly sedentary in stable habitats but predominately mobile in habitats subject to flooding. He reported movement upstream and downstream to be nearly equal, suggesting that the carp has no consistent pattern of movement but responds directly to local variations in habitat.

Brown Trout

The movement of brown trout in the study area in 1970 and 1971 is shown in Figure 11. Very little movement was

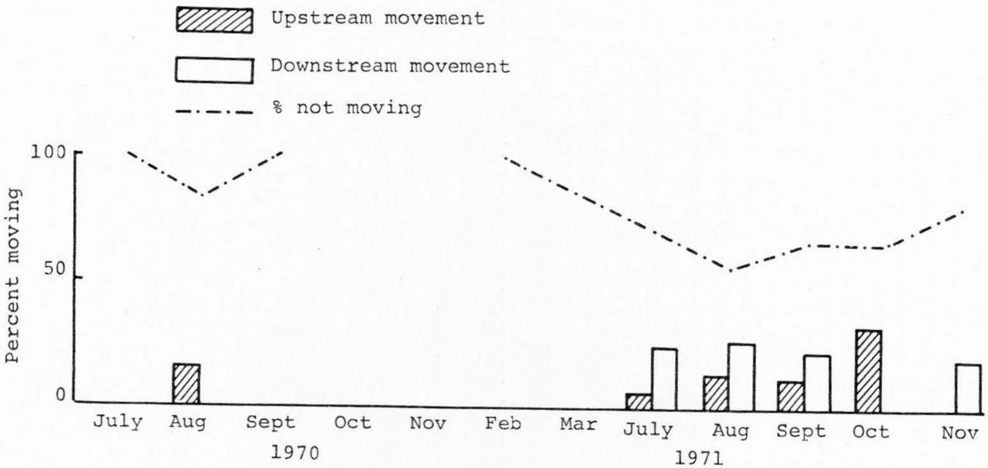

Figure 11. Movement of brown trout in the Logan River during 1970-1971.

apparent during the summer and fall of 1970 reflecting the low water levels at these times. During the summer of 1971 movements were predominately downstream, however, in October movements were entirely upstream followed by an apparent downstream return in November. This peak in upstream movement corresponds to the spawning season of the brown trout. Several authors have noted upstream migrations of brown trout during the spawning season (Shuck, 1943; Stefanich, 1951; Ball and Jones, 1960). Bridges and Neuhold (1968) found that movement of brown trout in the canyon section of the Logan River peaked in October. Movements at this time were predominately downstream, the reason for this being attributed to limited available spawning habitat in a tributary of the main river which forced the resident fish here to move downstream into the river proper.

A direct comparison with Matthews' (1966) brown trout movement data is possible. Again, his sections I, II, and III are comparable to section 1, 2 and 3; 4 and 5; and 6, 7 and 8 of the present study. By examining the relationship of location of recapture to location of previous capture in these three main sections using White's H (Table 20) it is possible to obtain some indication of the extent of overall movement within the population before and after the abatement of the sewage discharge. Consider again that .3333 is the minimum H value possible in a 3 x 3 contingency table. The value of .5682 for Matthews' data would indicate a

Table 20. Brown trout collections in the study area in 1965-1966 and 1970-1971 showing recapture location and number recaptured. 1965-1966 data from Matthews (1966).

1965-1966

Recapture location	I	II	III
III	2	2	4
II	3	21	3
I	32	4	0

(Columns: Location of previous capture)

N = 71
H = .5682

1970-1971

Recapture location	1-2-3	4-5	6-7-8
6-7-8	2	3	2
4-5	1	3	0
1-2-3	80	2	1

(Columns: Location of previous capture)

N = 94
H = .7664

moderately strong relationship between the two variables in 1965-1966 suggesting limited overall movement within the population. Matthews suggested that the movement that did occur (downstream in the spring, upstream in the summer) was due to improved water quality below the confluence of 7-Mile during the spring runoff and decreased water quality in the summer below 7-Mile as water levels dropped.

An H value of .7664 was obtained in the present study indicating a relatively strong relationship between location of capture and location of previous capture. This would suggest that only a small amount of movement is occurring in the brown trout population. Most of the movement that did occur was probably related to spawning activity. The apparent limited overall movement of the brown trout could be a reflection of the improved water quality of the river, particularly below 7-Mile Creek. Now that sewage is no longer discharged into the river, fish that move into the area below 7-Mile Creek may not be forced to move out of this area in response to intolerable water quality conditions. (Only one brown trout recaptured during the study moved upstream past the mouth of 7-Mile Creek.) The small number of brown trout below 7-Mile Creek and the resultant small return of marked fish in this area limits a more rigorous interpretation of apparent movement patterns in this section. It is likely however that the improved water quality below 7-Mile Creek has less of an adverse affect on both vertebrate and invertebrate forage organisms of the brown trout making the river more suitable for trout habitation than in the past.

Of 73 fish recaptured in the study area in 1965-1966 by Matthews, 79.1 percent were recaptured in the station of marking and release. Seven fish (9.6%) were recaptured upstream and nine fish (12.3%) were recaptured downstream from the station of release. In 1970-1971 the comparable percentages were 3.2 percent recaptured upstream; 90.4 percent recaptured in location of marking and 6.4 percent recaptured downstream, further reflecting an apparent reduced overall movement of brown trout in the study area.

These patterns were tested for independence and found to be significant at the 90 percent confidence level (Table 21).

The numbers and location of all brown trout recaptures made in 1970-1971-1972 and their location of previous capture are shown in Figure 12.

The movement patterns of brown trout following release are shown in Table 22. An initial downstream displacement was evident in the first ten day period following capture and release. In the 11 to 30 day period following release upstream movement predominated. The general movement pattern shown by the brown trout was similar to that observed in the whitefish and carp with an overall tendency toward downstream movement in a small percentage of the fish.

Table 21. Movement of recaptured brown trout (%) in the study area during 1965-1966 and 1970-1971. In a test for independence $\chi^2 = 5.81$ (tabular $\chi^2_{(2,.10)} = 4.61$).

Year	Percent moving		
	Upstream	None	Downstream
1965-1966	9.6	79.1	12.3
1970-1971	3.2	90.4	6.4

Location of recapture								
8					1			
7		1				1		
6			1	2				
5			1	1				
4				2				
3	2	3	25	1				
2	2	12	1	1				
1	30	3	2				1	
	1	2	3	4	5	6	7	8
	Location of previous capture							

Figure 12. Numbers and location of all brown trout recaptures made in 1970, 1971 and 1972.

Table 22. Movement patterns of brown trout following release.

Days since previous capture	Total number	Percent Moving Upstream	None	Downstream	H
1-10	19	5.3	73.7	21.0	.6421
11-20	19	15.8	73.7	10.5	.6244
21-30	14	14.3	85.7	0.0	.7902
over 30	42	9.1	72.7	18.2	.5381
All collections	94	9.7	72.2	16.1	.5050

Again this is probably a reflection of the collection technique rather than a directed movement on the part of the fish.

Utah sucker

Information concerning the movement of Utah suckers in the study area is unfortunately very limited. Of 691 suckers marked during the study, only 20 or 2.8 percent were recaptured. The distribution of location of these recaptures is shown in Figure 13.

In spite of the low recapture rate, the H value for the two years of the study was .3986 (Table 23) indicating a fair relationship between recapture location and location of previous capture. The low recapture rate might suggest extensive movement of suckers out of the study area, however the H value obtained would indicate that those fish which were recaptured demonstrated only limited movement. Another possibility which was supported by field observations is a high mortality among the suckers during the electrofishing operation. The suckers, more than any other species collected, appeared to be highly susceptible to physical injury when using the alternating current generator. Smith et al. (1946) reported shocking mortalities in a slosely related species, the white sucker, *Catostomous commersoni* when using alternating current.

Any fish collected which was under extreme stress was not released. Most of these fish when examined by dissection

Location of recapture	1	2	3	4	5	6	7	8	7-Mile
7-Mile						1			
8									
7	1								
6				1				1	
5		1			1				
4	1								
3		2		1	1				1
2	1	1	1						1
1	1	1	2						

Location of previous capture

Figure 13. Numbers and location of recaptured Utah suckers in the Logan River during 1970 and 1971.

Table 23. Movement patterns of Utah suckers following release.

Days since previous capture	Total number	Percent Moving Upstream	None	Downstream	H
1-10	6	50	16.6	33.3	a
11-20	2	50	0.0	50.0	a
21-30	4	25	0.0	75.0	a
Over 30	5	60	20	20	a
All collections	17	41.1	17.8	41.1	.3986

[a]Not calculated due to inadequate sample size.

revealed extensive internal hemorrhaging along the back bone invariably associated with a broken and sometimes shattered vertebral column. It is suspected that many of the fish released had suffered some degree of injury which was not immediately apparent but resulted in their death following release. This would in part account for the low recapture rate.

Of the recaptured fish, equal numbers (7) had moved upstream and downstream from their previous capture location. Three had moved out of 7-Mile Creek, two upstream to sections 2 and 3 and one downstream to section 6, immediately below the confluence of 7-Mile Creek and the Logan River. The relative movement patterns of recaptured suckers are shown in Figure 13.

The amount of information available in the literature concerning the movement of non-game fish in rivers is very limited. Stefanich (1951), in a Montana stream physically similar to the Logan River, reported a recapture rate of tagged white and long nose suckers of 4.5 percent. Only two of 35 fish recaptured had moved out of the 600 foot sections in which they had been tagged. He did note a drastic reduction of suckers in the summer suggesting a mass exodus of these species out of the study stream but gave no reason for this observed movement.

Rainbow Trout

Rainbow trout were seldom found in the study area in 1970. Of 12 fish tagged during this year only one was recaptured. Nine of the 12 were captured above the confluence of 7-Mile Creek. In 1971 rainbows were more abundant and were collected in all sections of the study area. The distribution and location of all recaptures made in both years are shown in Figure 14.

Based on the report of Bangeter (1965) and interviews of long time residents of the area along the river, rainbow trout have never been abundant in the study area.

It is suspected that the greater number of rainbows in the river in 1971 was the result of the high spring runoff. These fish apparently moved downstream from upper reaches of the river. Once in the study area they demonstrated very little movement. If they moved at all it was most often in an upstream direction. The calculated H value for all rainbow trout recaptured was .6440.

Movement of other species

Bullheads and green sunfish were not commonly found in the Logan River above 7-Mile Creek but were relatively abundant in 7-Mile Creek and in the river below the confluence of the two streams. Their respective distributions were essentially alike in 1970 and 1971 and both appeared to favor turbid sections of the study area with slow current and silt or mud bottoms.

Nine black bullheads were recaptured during the course of the study. None were recaptured out of the location in which they were initially tagged. One recapture was made in

Location of recapture \ Location of previous capture	1	2	3	4	5	6	7	8	7-Mile
7-Mile									
8									
7									
6						3			
5						1			
4				1				2	
3			2						
2	1	3							
1	1	1							

Figure 14. Numbers and location of recaptured rainbow trout in the Logan River during 1970 and 1971.

section eight and all others in 7-Mile Creek. In a closely related species, the yellow bullhead, Funk (1955) found very limited movement and classed the species as "sedentary."

Of 53 green sunfish tagged, six were recaptured. Five were recaptured in 7-Mile Creek, the location of their initial tagging and one was recaptured in section six after having moved downstream out of 7-Mile Creek. Limited movement and the establishment of distinct home ranges in green sunfish have been demonstrated in other studies of stream fishes (Gerking, 1953; Funk, 1955).

Three cutthroat trout were recaptured in the study area. One was tagged and recaptured in section 2 and one moved from section 6 upstream into 7-Mile Creek. The third fish was recaptured twice, moving upstream from section 7 to 6 and from 6 to 5.

None of the ten other species marked during the study were recaptured.

Age and Growth Studies

Whitefish

Calculated total lengths of whitefish at each annulus are shown in Table 24. Growth rates in the study area appear to have improved since Matthews' study in 1966. Calculated lengths were consistently larger, at least in their first five years of life, than those reported by Matthews. Growth was similar to that reported by Sigler (1951b) for the canyon

Table 24. Mean calculated total lengths and increments of growth of 1605 mountain whitefish collected in the study area of the Logan River, July 1971 - October, 1971.

Age class	Number of fish	Total length at capture	Annulus 1	2	3	4	5	6
I	680	176	125					
II	303	234	129	213				
III	252	277	131	213	274			
IV	222	309	130	213	278	311		
V	114	329	130	209	272	310	336	
VI	34	340	124	200	262	308	335	354
Grand average			128	212	274	310	336	354
Average annual increments			128	82	63	36	27	19
Number reaching age			1605	926	623	371	149	35

portion of the Logan River. A comparison of growth curves from the present study and from Matthews' and Sigler's studies are shown in Figure 15.

Length-weight relationships varied considerably due to seasonal weight changes which were also reflected in the mean monthly condition (K) factors (Table 25). Condition factors in 1970 declined steadily to low levels during the summer months reflecting conditions for poor growth at that time. A distinct increase in condition was noted in October and November of 1970. This was very likely caused by the influx of heavier fish from above the diversion dam which was removed from the river in September. The added plumpness of prespawning fish also contributed to the higher K factors in this group. After November, condition factors again declined until February when they began to increase, reaching a peak in July. (Monthly growth rates suggest that K was probably at its highest level in May and the July value of 1.160 was not the highest level attained.)

Growth rates of some individual year classes declined slightly during the summer and early fall of 1970 but declined sharply and steadily from July through November in the four oldest year classes during 1971 (Figure 16). The 0 and I age classes did not show this distinct decline in weight but rather demonstrated no growth or only a very slight increase in weight. These somewhat unexpected growth patterns appear to be related to the availability of

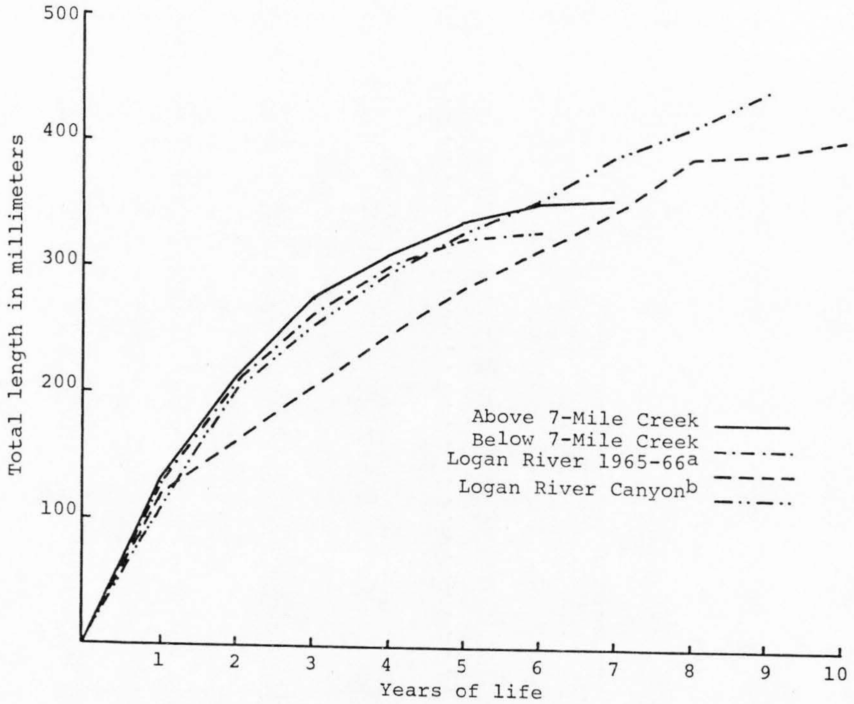

Figure 15. Growth curves of whitefish in the Logan River. [a]from Matthews (1966), [b]from Sigler (1951).

Table 25. Length-weight relationships and mean condition factors (K_{TL}) of mountain whitefish in the Logan River. Length-weight relations are expressed logarithmically in the form log (weight) = a + b log (length).

Date	n	Intercept (a)	Slope (b)	Correlation coefficient	Condition factor (K)
June 1970	107	-4.423	2.773	.961	1.064
July	214	-5.227	3.095	.986	1.014
Aug.	51	-5.726	3.283	.959	.927
Sept.	16	-5.657	3.243	.990	.878
Oct.	80	-5.442	3.184	.988	1.025
Nov.	5	-3.351	2.314	.989	1.015
Feb. 1970	69	-4.510	2.793	.969	.938
Mar.	65	-2.931	2.161	.895	.948
July	545	-4.626	2.870	.973	1.160
Aug.	536	-4.751	2.908	.954	1.102
Sept.	168	-5.165	3.075	.984	1.041
Oct.	193	-4.926	2.972	.981	1.024
Nov.	24	-4.807	2.915	.963	.970
Jan. 1972	17	-4.260	2.694	.894	.920

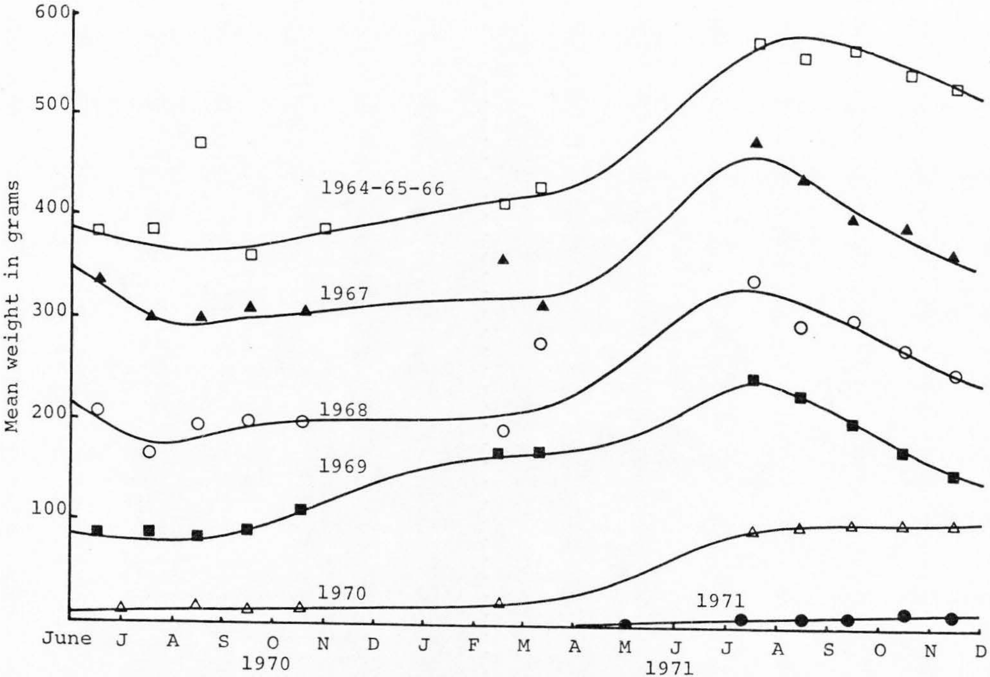

Figure 16. Growth of mountain whitefish year classes in the Logan River during 1970 and 1971.

invertebrate forage organisms during the summer and fall months. Erman (1968), in a study of the invertebrate fauna in the lower Logan River, found the biomass of invertebrates in July to be less than one tenth what it was in February. Hynes (1970) describes seasonal fluctuations in stream invertebrate biomass similar to those reported by Erman. Following the low levels of available forage in the summer and fall it is possible that temperature becomes limiting to growth, further reducing the likelihood of positive growth rates. McHugh (1941) lists food and temperature as two important factors affecting the growth rate of whitefish. That the two smallest age classes did not demonstrate negative growth rates during the summer likely reflects their ability to maintain themselves on the small early instars of insects available at this time. Laakso (1950) reported that fingerling whitefish used the same food organisms as did adults but consumed smaller numbers and sizes. A thorough discussion of food size-density requirements of fish can be found in Ivlev (1961).

To compare years of relatively good and poor growth rates in the whitefish population, growth data from the present study were combined with those from Matthews (1966). This resulted in a continuous record of calculated growth rates of whitefish from 1958 through 1970. It should be pointed out that the fish used from both studies came from throughout the study area rather than from either above or below 7-Mile Creek. Matthews' standard length measurements were converted to total length using his conversion formula (T.L. = S.L. x 1.22703) to obtain lengths comparable to the present data. The mean annual growth increments, excluding growth in the first year of life, were calculated for the entire period. Deviations from the mean growth increment are plotted in Figure 17. The general upward trend in growth from 1961, which essentially continues through the last few years of Matthews' data and the first of the present study, would seem to support the validation of both growth studies.

Since 1965 it appears that the mean annual deviations in growth are more predictable than they were prior to this time. It is conceivable that the large fluctuations in growth in the early 60's were related to the sewage discharge in the river, however considering the distribution of whitefish in the river at that time (based on Matthews' study) and the mobile nature of the species, the cause and effect relationships here are difficult to define.

Carp

Mean calculated total lengths of 159 carp collected in the study area during January and February 1972 are shown in Table 26.

Growth rates of carp in the study area are considerably lower than those reported for most other carp populations. A comparison of growth curves from three other Utah

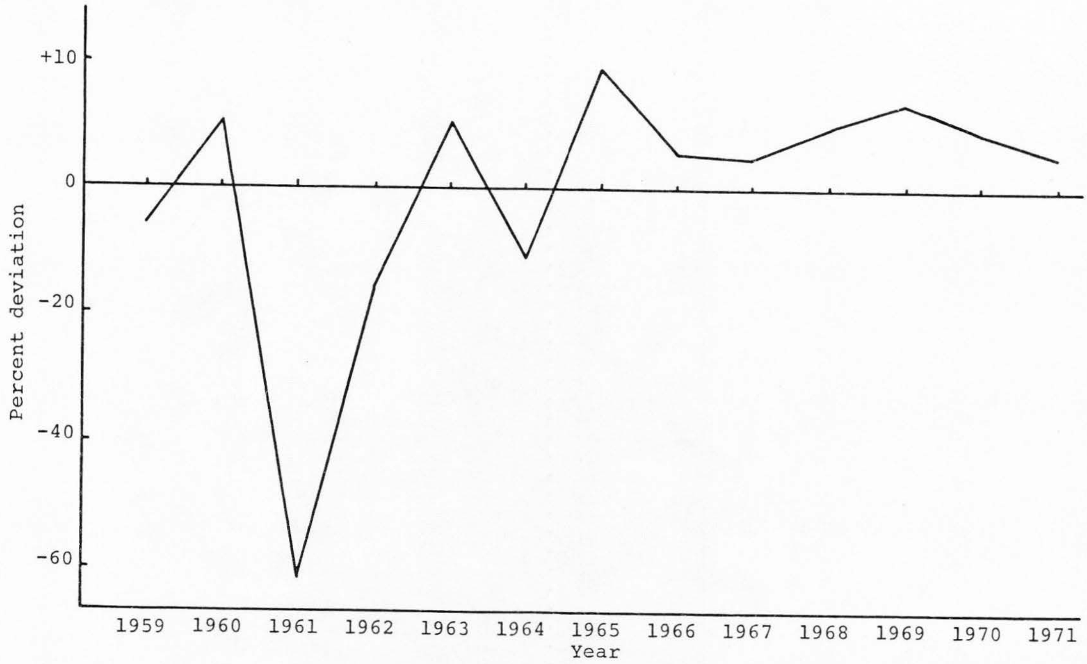

Figure 17. Deviations from mean annual growth increment of whitefish in the Logan River from 1959 to 1970.

Table 26. Mean calculated total lengths of 159 carp collected in Logan River during January and February 1972.

Age Class	No	Mean TL at Capture	Age I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII
I			-																
II			-	-															
III			-	-	-														
IV	1	323	141	236	283	310													
V	7	448	157	269	317	376	412												
VI	15	464	173	244	318	366	408	438											
VII	17	434	152	217	269	310	346	381	411										
VIII	22	468	151	229	287	330	368	400	427	450									
IX	24	491	147	212	272	315	359	400	420	453	473								
X	25	499	157	220	271	314	349	381	410	436	462	482							
XI	20	509	158	210	253	296	332	364	394	425	450	471	495						
XII	11	530	156	218	259	295	329	363	387	425	449	472	494	513					
XIII	6	515	150	191	228	262	309	330	356	392	411	437	463	481	503				
XIV	3	533	155	203	248	278	308	324	340	373	400	428	456	475	493	514			
XV	3	553	175	220	259	290	332	359	381	408	430	448	470	488	506	531	545		
XVI	2	555	177	212	248	276	311	333	368	386	407	434	467	488	509	520	532	548	
XVII	3	549	137	129	221	244	264	305	329	357	383	401	429	452	470	490	505	522	536
Grand Average			156	219	267	304	340	365	384	411	429	447	468	485	496	514	527	535	536
Average Annual Increment			156	63	48	37	36	25	19	27	18	18	21	15	13	18	13	8	1
Number of Fish Reaching Age			159	159	159	159	158	151	136	119	97	73	48	28	17	11	8	5	3

populations is shown in Figure 18. Growth of carp in Bear Lake, which is considered marginal habitat for carp (McConnell et al., 1957), is exceeded by growth of Logan River carp only during the first five years of life. Beyond five years, growth in the lake exceeds that in the river. Sigler (1958) reported growth of carp in Cache Valley ponds as being nearly identical to that in Bear Lake.

The poor growth of carp in the river was further reflected in a tagged carp collected on August 31, 1970. This fish had originally been tagged in the Logan River by the Utah Division of Wildlife Resources on July 9, 1964 just south of the Valley View Bridge. Its total length and weight at that time were 500 millimeters and 1600 grams. Its age was estimated at ten years (Bangerter, 1970). When recaptured in 1970 its total length was 515 millimeters and it weighed 1595 grams. It demonstrated virtually no growth during the previous six year period.

Deviations from the mean annual growth increment are shown in Figure 19 for the years 1959 to 1971. It is tempting to attribute the poorer growth after 1967 to the abatement of the sewage discharge in the river. Of all the fish collected during the study the carp is probably the most adept at living (and actually thriving) in a polluted environment such as existed below 7-Mile Creek prior to 1968. Because of its ability to do well in such a situation, elimination of the sewage effluent could very possibly have

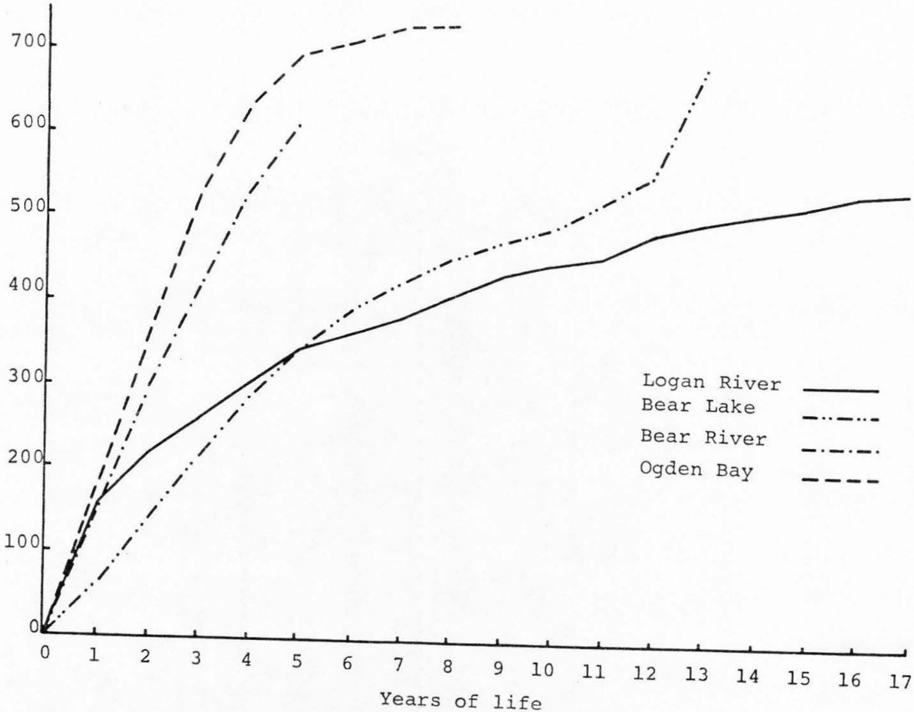

Figure 18. Growth curves of carp from the Logan river, Bear Lake, Bear River and Ogden Bay, Utah. Data from the latter three areas from Sigler (1958).

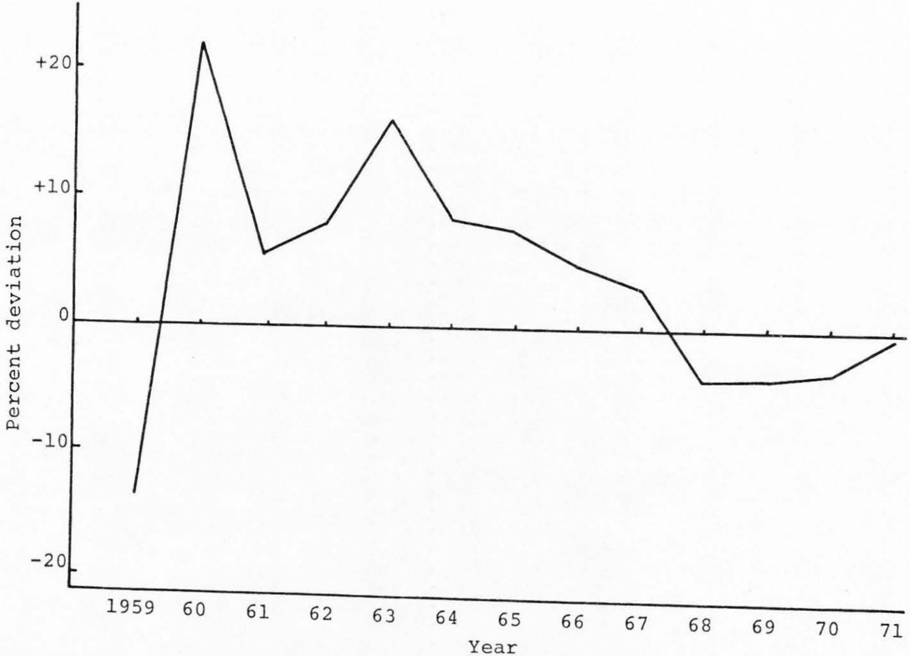

Figure 19. Deviations from mean annual growth increment of carp in the Logan River from 1959 to 1971.

reduced the total energy available to the carp population causing the decreased growth observed.

In other species examined in this manner, deviations in growth after 1967 were not as pronounced. Whitefish and brown trout demonstrated improved growth after 1967 while sucker growth was variable. Since the sucker is more closely related to the carp from a functional standpoint than the other two species, its observed growth patterns after the sewage abatement might lend some additional credence to the hypothesis that carp growth was reduced as a result of the sewage abatement.

Although carp exhibited slow growth rates, their condition factors were not particularly low, ranging from 1.248 to 1.593 (Table 27).

In 1970 condition factors above 7-Mile Creek were significantly higher than below (t-test at 95 percent confidence level). Several investigators have concluded that population density is the most significant factor controlling growth in fish (Beckman, 1941; Grice, 1957). Average annual standing crops of carp in the Logan River above and below 7-Mile Creek were 1091 kg/ha and 760 kg/ha respectively. These densities are both greater than the maximum of about 600 kg/ha reported for North American lakes and reservoirs by Carlander (1955).

In a study on the bear River, Utah, Robel (1962) found weight increases in pen held carp to be negatively correlated

Table 27. Length weight relationship and condition factors of carp in the Logan River 1970-1971.

Month	Number of fish	Intercept (a)	Slope (b)	Correlation coefficient	Mean condition factor
Above 7-Mile Creek					
June 1970	30	-3.647	2.541	.941	1.365
July	235	-3.864	2.611	.971	1.335
Aug.	259	-4.318	2.745	.988	1.294
Sept.	16	-3.751	2.580	.978	1.320
Oct.	34	-4.105	2.705	.986	1.291
Feb. 1971	75	-4.058	2.686	.940	1.275
Mar.	23	-4.293	2.776	.983	1.273
July	110	-4.233	2.769	.934	1.438
Aug.	242	-4.424	2.831	.990	1.375
Sept.	64	-3.349	2.427	.843	1.353
Oct.	21	-4.528	2.877	.993	1.423
Below 7-Mile Creek					
July	157	-4.361	2.794	.989	1.267
Aug.	63	-4.449	2.847	.998	1.304
Sept.	53	-4.216	2.734	.994	1.258
Nov.	48	-3.265	2.391	.956	1.248
July 1971	75	-3.632	2.533	.893	1.406
Aug.	128	-4.620	2.900	.980	1.324
Sept.	18	-4.744	2.951	.989	1.354
Oct.	20	-5.201	3.121	.983	1.337
7-Mile Creek					
June 1970	75	-3.749	2.567	.977	1.593
July 1971	117	Not calculated		-	1.491
Aug.	85	-4.700	2.936	.997	1.387
Sept.	33	-4.579	2.889	.993	1.379
Oct.	15	Not calculated		-	1.351

with population density. His stocking densities were 224 kg/ha, 448 kg/ha and 672 kg/ha.

Condition factors both above and below 7-Mile Creek were significantly higher in 1971 than in 1970 suggesting that even carp, which are generally readily adaptable to rigorous habitat conditions, were adversely affected by the low flow rates in 1970.

The low growth rates of carp in the Logan river may be attributed in part to the dense population present. The low flows periodically encountered would also appear to contribute to the reduced growth by crowding the fish during these periods. This generally occurs coincidentally with a temperature regime which would seemingly favor rapid growth. However, add to this the cyclic pattern in invertebrate forage density with lowest levels occurring during the low flow periods and the population density-food density factors become confounded with the resulting minimal growth observed.

Brown trout

Growth rates of brown trout in the study area during 1970-1971 were greater than those reported by Sigler (1951a) for the canyon portion of the Logan River, and during the first two years of life, were greater than in several other brown trout growth studies summarized by Carlander (1969). Growth rates slowed however in the older year classes and the calculated length of five year old fish were considerably less than the minimum mean length reported for several other studies. Mean calculated total lengths and annual increments of growth are presented in Table 28. Growth curves of brown trout in the study area are compared with those from other habitats in Figure 20.

The seasonal variations in the length-weight relationships and condition are shown in Table 29. The variations in condition factor are almost identical to those seen in the whitefish population with declines throughout the summer and fall and a peak in the spring. Again, as was observed in the whitefish, weight losses in the summer months were most pronounced in the older and larger fish (Figure 21). One and two year old fish appear to grow primarily during the spring. In 1971 these first two age classes demonstrated essentially no growth from July through December.

The age 3+ trout showed a decided drop in mean weight during July and August in both years. Examination of mean lengths of these same fish also showed a slight decline during this time period, being less pronounced in 1970 than in 1971. This suggests that movement in or out of the study area was occurring. It would appear at first that movement of the larger individuals of these year classes out of the study area was causing the decreasing mean weights. Analysis of variance of the weights of all brown trout recaptured during this period however indicated no significant difference in weights of upstream, downstream or nonmigrants. Only

Table 28. Mean calculated total lengths and annual increments of growth of 432 brown trout collected in the study area of the Logan River, 1970-1971.

Age class	Number of fish	Total mean length at capture	1	2	3	4	5
I	145	223	150				
II	167	293	142	226			
III	95	342	136	212	279		
IV	23	369	136	207	271	319	
V	2	439	121	196	269	318	358
Grand average			143	220	278	319	358
Average annual increment			137	77	58	41	39
Number reaching age			432	287	120	25	2

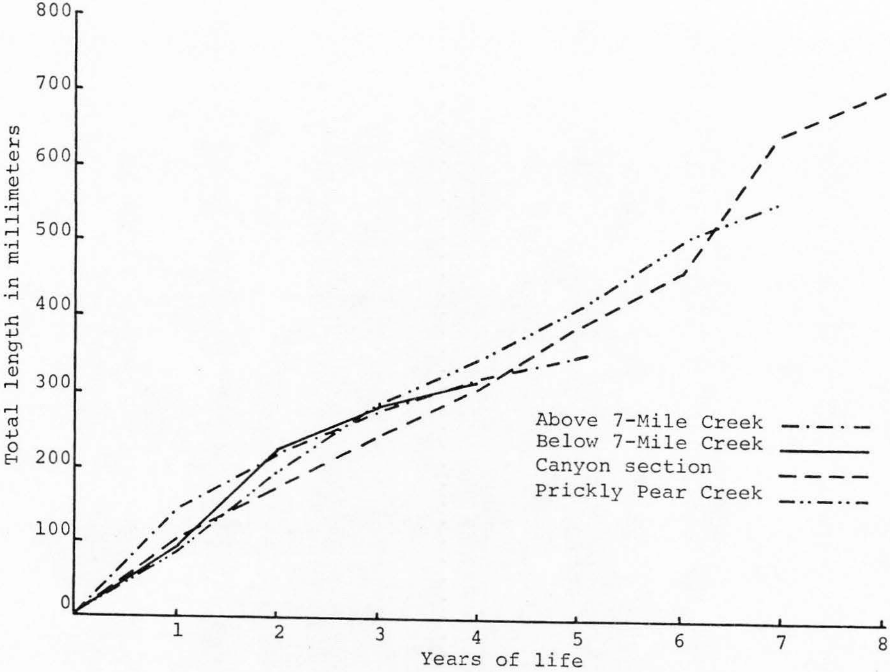

Figure 20. Growth curves of brown trout in the Logan River study area in 1970-1971, the canyon portion of the Logan River (Sigler, 1951) and Prickly Pear Creek, Montana (Bishop, 1955).

Table 29. Length weight relationships and condition factors of brown trout in the Logan River 1970-1971.

Month	Number of fish	Intercept (a)	Slope (b)	Correlation coefficient	Condition factor (K)
June 1970	7	-3.969	2.605	.941	1.180
July	65	-5.298	3.127	.994	1.031
August	65	-5.381	3.162	.993	1.020
September	2			-	.974
October	4	-4.477	2.767	.967	.933
Jan.-Feb.1971	11	-2.942	2.152	.786	1.015
March	7	-3.770	2.487	.993	.866
July	99	-5.005	3.043	.980	1.283
August	144	-5.369	3.176	.984	1.168
September	32	-6.104	3.463	.945	1.088
October	25	-5.297	3.126	.993	1.026
November	5	-6.158	3.433	.914	.916

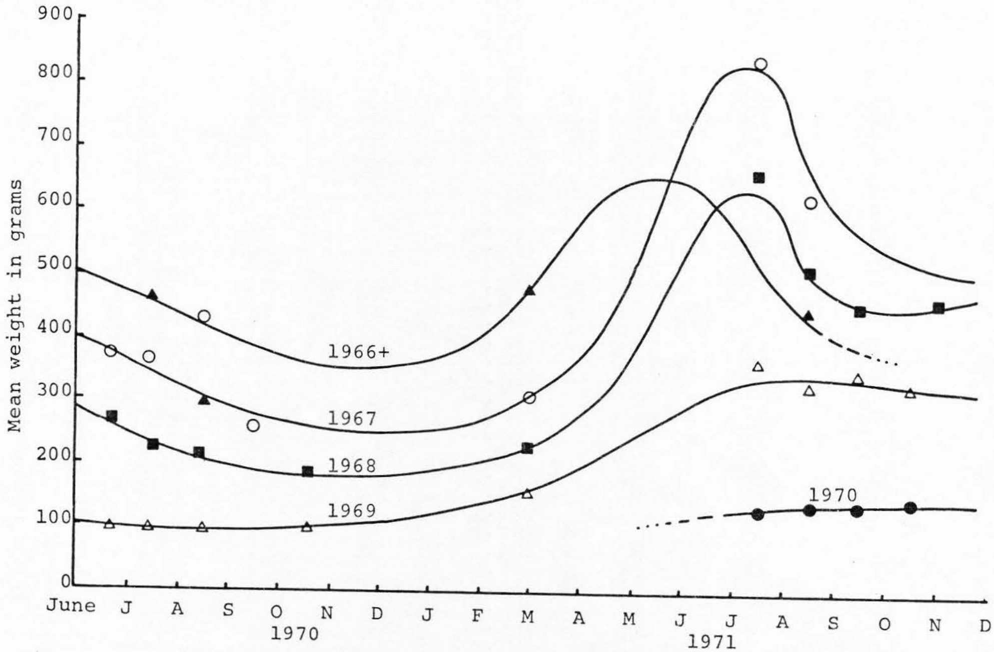

Figure 21. Growth of brown trout year classes in the Logan River during 1970 and 1971.

14.6 percent of the fish which had been tagged and recaptured during this period had positive instantaneous growth rates while 78.0 percent had negative instantaneous growth rates.

The detrimental effects of the tag might be suspect here as the cause of the decreased growth rates. A comparison of length weight regression lines for fish tagged from 1-10, 11-20, 21-30 and over thirty days respectively with untagged fish collected during the same time period indicated no significant differences in the length-weight relationship at any time indicating that adverse effects of the tage were not significant in affecting growth rates. It therefore appears that movement in and out of the study area and negative growth were confounded during July, August and September causing the drop in mean weight of the 3+ aged brown trout observed.

The age 1 and 2 brown trout, although not declining in weight during the summer of 1971, also did not grow during this period suggesting marginal habitat conditions at this time.

During 1970 the poor growth during the summer was probably due to three factors interacting: high water temperatures, a decline in insect forage organisms and poor water quality. During 1971 water temperatures were near optimal for growth and the moderately high flow rates contributed to a fairly "good" water quality. A decline in the insect forage base at this time due to emergence appears to be the most likely explanation for the depressed growth during the summer of 1971.

The deviation from the mean annual growth increment are shown in Figure 22. In spite of the small number of year classes found in the river a distinct increasing trend in growth is evident since 1966 possibly suggesting generally improved habitat conditions since that time.

Utah sucker

Very little is known about the life history of the Utah sucker. Early studies of the fish were concerned primarily with the taxonomic classification of the species (Cope and Yarrow, 1875; Jordan, 1875; Jordan and Gilbert, 1881; Tanner, 1936). Simon (1946) and Miller (1952) comment briefly on the spawning behavior and habitat preference of the species but it was not until the work of McConnell et al. (1957) on Bear Lake, Utah that age, growth and other parameters were studied in a specific population. In this study scales were assumed to be reliable indicators of age and growth. In studies of closely related suckers, several other investigators have shown that scales were reliable and useful in determining age and growth relationships (Hayes, 1956; Parker, 1958). In the present study there was no reason to believe that scales would be less reliable. A fairly uniform relationship existed between anterior scale

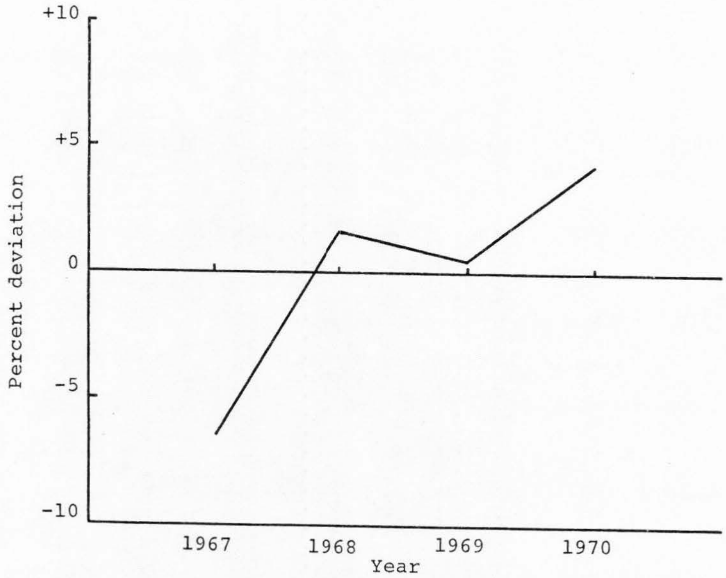

Figure 22. Deviations from mean annual growth increment of brown trout in the Logan River from 1967 to 1970.

radius and total length and the number of annuli increased regularly with an increase in size of the fish. Any scale on which annuli were not clearly evident was discarded. For these reasons it was felt that sucker ages were correctly identified. The calculated total lengths of suckers in the study area at each annulus are shown in Table 30.

A comparison of the growth curves of fish from Bear Lake and the study area is shown in Figure 23. Growth rate of suckers in the Logan River appears to be quite good. Seasonal fluctuations in condition factor are evident (Table 31) which are strikingly similar to those shown by the whitefish and brown trout with the characteristic decline during the summer months and increase during the fall and winter. The mean condition factor above 7-Mile Creek in 1971 was significantly higher than in 1970. Below 7-Mile Creek the difference was not significant (t-test at 95 percent confidence level). This would seem to suggest that the affects of reduced flow and the associated degradation of sucker habitat above 7-Mile Creek was more severe in this area than below. The lower region of the river is larger and more uniform and changes in water depth and velocity associated with seasonal flow patterns would not be likely to cause great changes in the overall habitat. This contention is supported in part by the work of Katz and Howard (1954) in Lytle Creek, Ohio, in which they found the

Table 30. Mean calculated total lengths of 208 Utah suckers collected in the study area of the Logan River during 1971.

Age class	Number of fish	Total length at capture	1	2	3	4	5	6	7	8	9
I	6	141	101								
II	4	226	106	194							
III	3	296	111	294	314						
IV	15	386	97	202	312	392					
V	36	406	95	191	290	369	421				
VI	54	411	88	166	262	343	400	433			
VII	52	441	88	162	258	336	391	426	448		
VIII	28	460	93	179	260	329	380	420	447	464	
IX	10	480	99	165	258	346	399	435	454	470	479
Grand average			92	176	270	348	398	428	449	466	480
Annual increment			92	84	94	79	54	35	24	17	10
Number reaching age			208	202	198	195	180	144	90	38	10

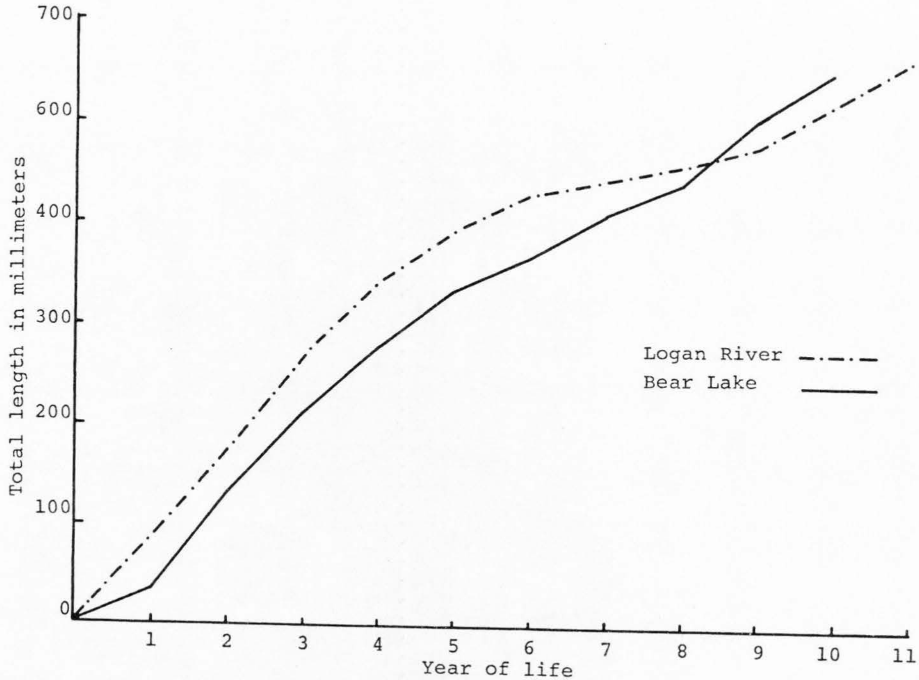

Figure 23. Growth curves of Utah suckers from the Logan River and Bear Lake, Utah (McConnell et al., 1957).

Table 31. Length-weight relationship and condition factors of Utah suckers in the Logan River 1970-1971.

Month	Number of fish	Intercept (a)	Slope (b)	Correlation coefficient	Mean condition factor (K_{TL})
Above 7-Mile Creek					
June 1970	23	-4.779	2.953	.928	1.253
July	74	-4.982	3.024	.976	1.224
Aug.	44	-4.887	2.976	.999	1.157
Sept.	2	Not calculated		-	1.193
Oct.	27	-5.140	3.083	.977	1.212
Feb. 1971	36	-5.870	3.367	.964	1.301
Mar.	8	-3.173	2.373	.963	1.368
July	19	-5.698	3.309	.939	1.383
Aug.	73	-4.395	2.784	.984	1.555
Sept.	49	-5.309	3.149	.994	1.218
Oct.	20	-4.981	3.032	.989	1.295
Below 7-Mile Creek					
July 1970	28	-5.091	3.068	.998	1.216
Aug.	69	-4.777	2.939	.967	1.157
Sept.	13	-4.744	2.908	.941	1.060
Nov.	11	-5.677	3.279	.978	1.173
July 1971	2	Not calculated		-	1.283
Aug.	32	-4.516	2.852	.940	1.247
Sept.	7	-4.937	2.993	.939	1.114
Oct.	6	-3.800	2.574	.992	1.188
7-Mile Creek					
June 1970	11	-4.735	2.933	.999	1.256
July 1971	7	-5.239	3.131	.999	1.199
Aug.	22	Not calculated		-	1.069
Sept.	14	-5.000	3.016	.998	1.106
Oct.	9	-5.042	3.035	.999	1.110

growth of the creek chub, *Semotilus atromaculatus*, to be less in a section of stream with reduced flow than in a downstream section having a greater flow rate.

The deviations from the mean annual growth increment are shown in Figure 24. Years of poorest growth generally followed years of near minimum summer flow rates although this relationship is not strong.

Other species

The annual growth rates of several less abundant species in the river were calculated. These include rainbow trout, Utah chub, cutthroat trout and green sunfish. The mean calculated total lengths and increments of growth for these species are presented in Tables 32 through 35.

No rainbow trout over four years old were found in the river. Calculated growth at each annulus was generally greater than in most studies reported by Carlander (1969) particularly for the first year of growth. This, however, probably reflects the hatchery origin of the fish rather than the suitability of the river as rainbow trout habitat. The mean condition factor of 20 untagged fish (1.088) was nevertheless, higher than most reported in the literature.

During their first two or three years, growth of Utah chubs in the Logan River generally exceeded the growth reported in other Utah habitats (Carbine, 1936; McConnell et al., 1957). In older fish, growth appears to be relatively slow. By the time the fish are over three years old

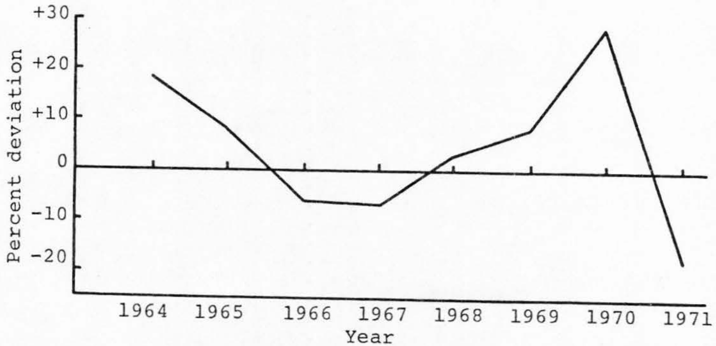

Figure 24. Deviations from mean annual growth increment of Utah suckers in the Logan River from 1964 to 1971.

Table 32. Mean calculated total lengths of 39 Rainbow trout collected in the Logan River during 1970-1971.

Age class	Number of fish	Total length at capture	1	2	3	4
I	10	296	187			
II	17	318	125	238		
III	10	358	123	213	295	
IV	2	378	118	209	274	326
Grand average			138	220	284	326
Annual increment			188	82	64	42
Number reaching age			39	29	12	2

Table 33. Mean calculated total lengths of 12 Utah chubs collected in the Logan River during 1970-1971.

Age class	Number of fish	Total length at capture	1	2	3	4	5	6	7	8
I	1	160	97							
II	0	-	-	-						
III	2	203	96	148	175					
IV	3	185	46	97	147	164				
V	2	196	74	116	148	163	182			
VI	0	-	-	-	-	-	-	-		
VII	3	227	49	89	123	149	175	196	211	
VIII	1	220	31	71	111	146	169	185	200	211
Grand average			63	105	142	157	177	193	208	211
Annual increment			63	42	37	15	20	16	15	3
Number reaching age			12	11	11	9	6	4	4	1

Table 34. Mean calculated total lengths of 13 Cutthroat trout collected in the Logan River during 1970-1971.

Age class	Number of fish	Total length at capture	1	2	3
I	8	245	152		
II	4	304	147	256	
III	1	395	198	312	359
Grand average			154	267	359
Annual increment			154	113	92
Number reaching age			13	5	1

Table 35. Mean calculated growth rates of 19 Green sunfish collected in the study area in 1970-1971.

Age class	Number of fish	Total length at capture	1	2	3	4	5	6	7
I	4	73	35						
II	4	114	36	78					
III	7	125	35	71	101				
IV	3	130	34	75	97	117			
V	0	-	-	-	-	-	-		
VI	0	-	-	-	-	-	-	-	
VII	1	175	21	59	79	103	115	176	163
Grand average			36	74	97	114	115	136	163
Annual increment			36	38	23	17	1	21	27
Number reaching age			19	15	11	4	1	1	1

(approximately 150 mm in total length) it is likely that they are in direct competition for available resources with the more abundant whitefish and brown trout in the river. Hazzard (1935) states that Utah chubs compete directly with trout in Utah Lake. It is also probable that their decline in abundance in the river was in part related to increases in the two aforementioned species in the lower reaches of the river.

No cutthroat trout over three years of age were collected in the river. Fleener (1951), in collections from the canyon portion of the Logan River also did not find any fish over three years old. Calculated growth rates of cutthroats in the river were greater than in most stream studies summarized by Carlander (1969) including collections from the canyon portion of the river. The abundance of cutthroats in the river is probably limited by reduced spawning habitat and competition with other species for food and possibly cover.

Green sunfish were not abundant in the Logan River although they were consistently collected in 7-Mile Creek. The majority of those used for determining age and growth relationships were collected in 7-Mile Creek. Growth rates were less than those reported by Sigler (1963) for other Northern Utah populations. The mud and silt bottom, constant turbidity and extremes in flow and temperature in 7-Mile Creek may contribute to the slow growth in this population.

Fish Production

Whitefish

Population estimates of whitefish above and below 7-Mile Creek are shown in Figures 25 and 26 respectively. The population curves were fitted to the individual population estimates by inspection. During intervals between population estimates, subjective estimates of the population size were made based on field observations and movement data. In September 1971, Delury estimates of population size were made in sections 2, 3, and 4. When the results were projected to the river above 7-Mile Creek there was close agreement with estimates based on the Peterson method indicating that the point estimates used were perhaps better than the confidence intervals might indicate.

The whitefish population in the study area appears to have declined considerably from previous levels. During 1965-1966 Matthews (1966) reported a yearly average of 1150 whitefish per mile in the study area above 7-Mile Creek and approximately 135 per mile below 7-Mile Creek. During the present study the annual average population size was 428 whitefish above and 103 fish per mile below 7-Mile Creek.

Production curves for mountain whitefish in the Logan River above and below 7-Mile Creek are presented in Figures 27 and 28.

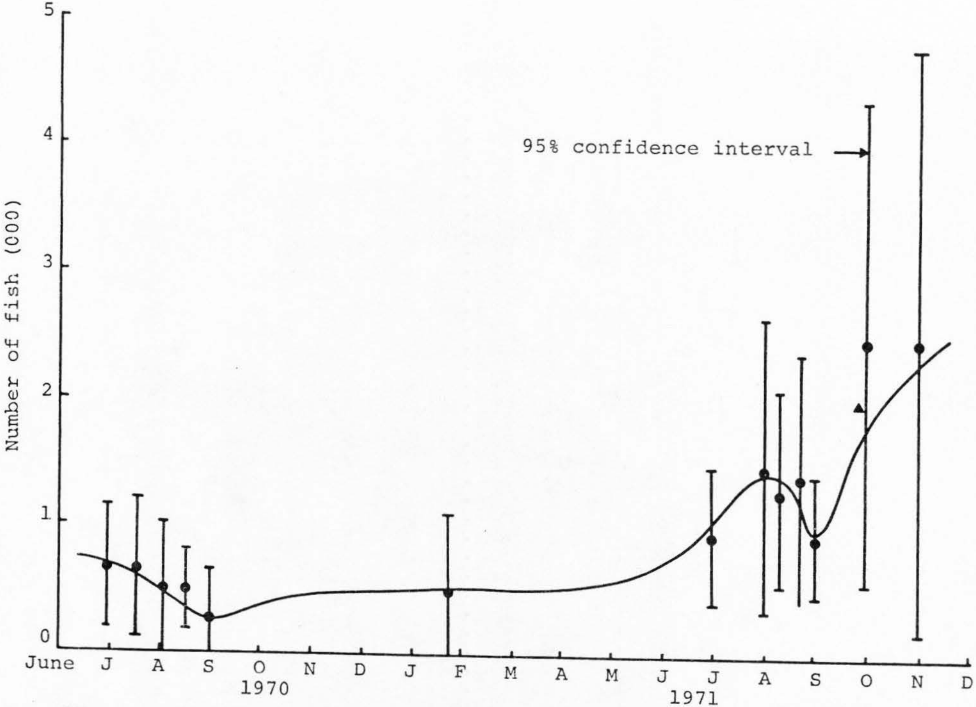

Figure 25. Population curve of mountain whitefish in the Logan River above 7-Mile Creek during 1970 and 1971. Triangle indicates Delury population point estimate.

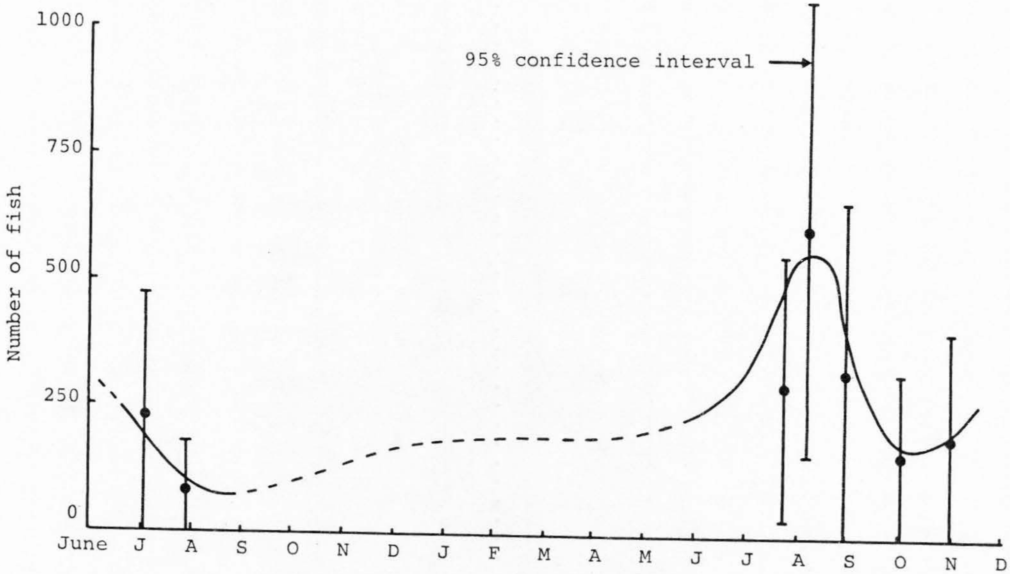

Figure 26. Population curve of mountain whitefish in the Logan River below 7-Mile Creek during 1970 and 1971.

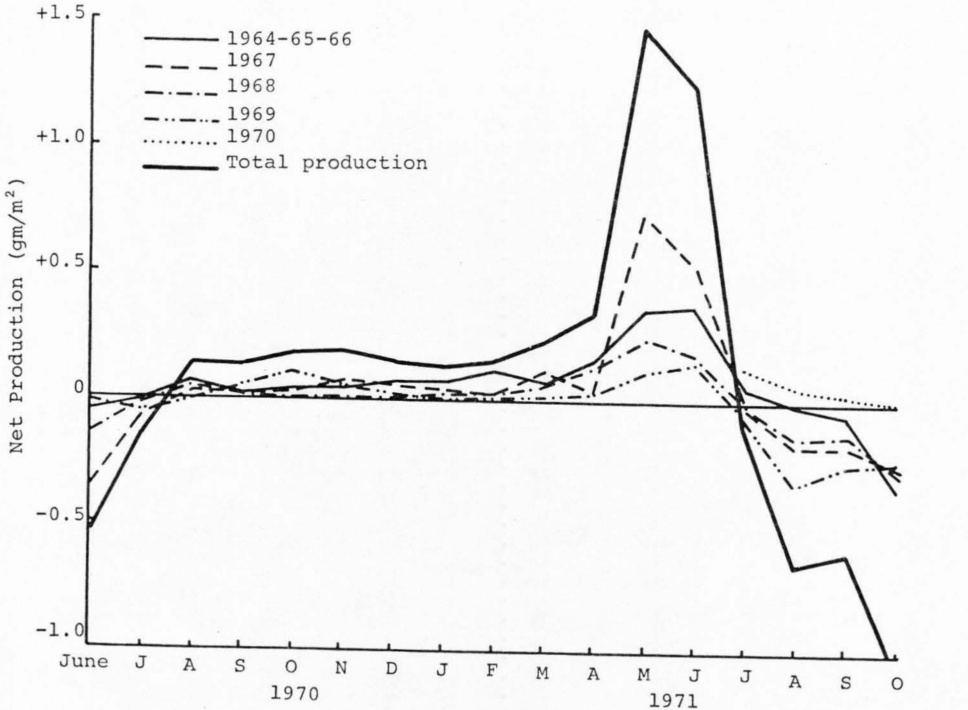

Figure 27. Production curves of mountain whitefish year classes in the Logan River above 7-Mile Creek during 1970 and 1971.

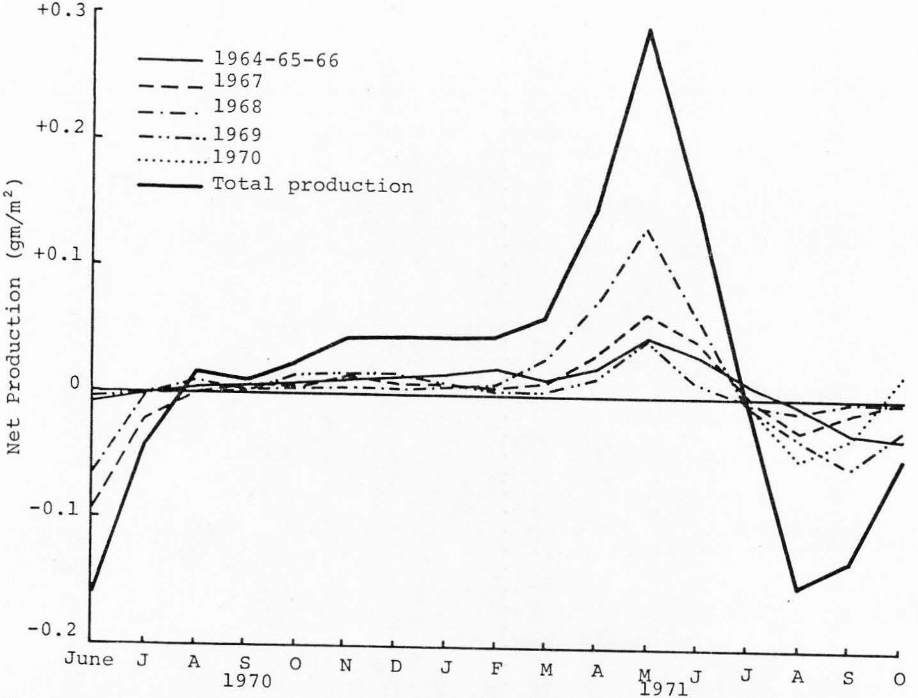

Figure 28. Production curves of mountain whitefish year classes in the Logan River below 7-Mile Creek during 1970 and 1971.

In estimating production of age 0 whitefish, the descending slope of catch per effort through time was used to calculate i, the instantaneous mortality rate in the exponential growth model. It was assumed to be the same in both 1970 and 1971. By knowing the growth rate and having estimates of i and a single population estimate it was then possible to make a rough estimate of total net production of this age class. For the period from 1 June 1970 to 1 June 1971 production of this age class above and below 7-Mile Creek was 1.1315 gm/m^2 and .9961 gm/m^2 respectively.

Seasonal changes in whitefish production clearly reflect growth patterns. Maximum production occurred during May 1971. A negative net production was observed during the summer months in both 1970 and 1971. In 1970 production rose to slightly above maintenance levels by August and remained there through March. In 1971 maintenance levels were not reached by October although above 7-Mile Creek net weight losses to the population were declining at this time. Below 7-Mile Creek net weight losses continued through October.

Estimates of production of gonadal products were based on mean gonad weight differences of pre and post spawning fish (Figures 29 and 30). Because of the difficulty of obtaining fish either immediately before or after spawning, these estimates should be considered minimal. If fish were collected before spawning, maximum gonadal development would

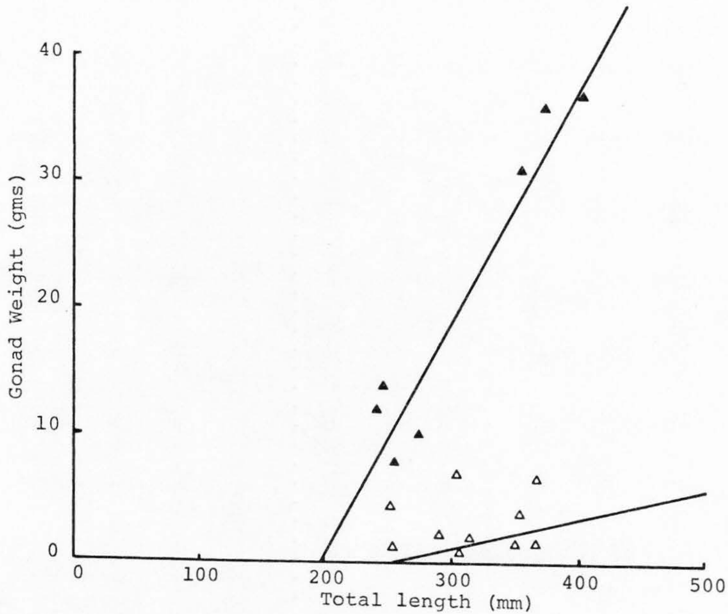

Figure 29. Total length-gonad weight relationships in pre and post spawning male whitefish. Solid dots indicate prespawning fish, open dots indicate post spawning fish.

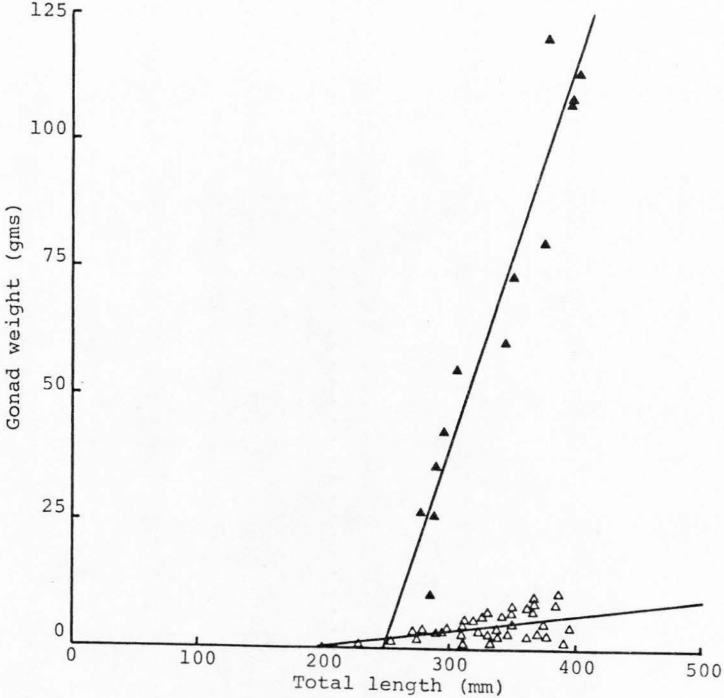

Figure 30. Total length-gonad weight relationships in pre and post spawning female whitefish. Solid dots indicate pre spawning fish, open dots indicate post spawning fish.

not yet have occurred. Following spawning one would expect, in the females at least, that gonad weight would be zero and only one regression line would be needed to estimate gonad weight losses, the other being the abscissa. However, because all eggs were not shed during spawning and new ovaries were already developing, the post-spawning regression lines in these Figures were used to obtain an estimate of the lower limit of weight loss.

For purposes of estimating gonad production the following assumptions were made: 1) growth in length was not occurring between the pre and post-spawning period, 2) spawning occurred over a relatively short interval, and 3) all sexually mature fish in the river spawned in the study area.

Based on the number of spent spawners in the river, and the degree of development of eggs collected in the river during late November, November 1st was chosen as the approximate date of spawning. Water temperature on this date was also consistent with Brown's statement (Brown, 1952) that stream populations do not spawn until temperatures drop to 42° F.

Mean weight losses due to spawning were calculated as the algebraic difference between the pre and post spawning regression lines at the mean length of the fish at spawning. The values obtained were assumed to be the same in both 1970 and 1971. In 1970 gonadal production above and below 7-Mile Creek was .8007 gm/m^2 and .1507 gm/m^2 respectively (Table 36).

Table 36. Estimated whitefish gonad production in the Logan River 1970-1971.

	Mean pre to post spawning weight loss (gms)	Estimated spawning population[a]	Estimated total weight loss due to spawning (gms/m^2)
1970			
Above 7-Mile Creek			
Females	60.4	298	.6740
Males	18.6	182	.1267
Below 7-Mile Creek			
Females	60.4	65	.1270
Males	18.6	40	.0240
1971			
Above 7-Mile Creek			
Females	60.4	1178	2.6643
Males	18.6	722	.5028
Below 7-Mile Creek			
Females	60.4	140	.2736
Males	18.6	85	.0511

[a]Based on November 1st population.

This accounted for 20.6 percent and 9.1 percent of total production in the two areas.

To obtain an estimate of total production (Table 37) gonad production was added to production of somatic tissue (Chapman, 1968).

Goodnight and Bjornn (1971) present the only other known estimate of mountain whitefish production. They considered their estimate of 7.07 $gm/m^2/yr$ (which included only the summer growth period and no estimate of gonad production) to be somewhat lower than might be expected for a species which comprised 60 to 80 percent of the total biomass of the fish population. They attributed this low production in part to an underestimation of the abundance of age 0 fish, but mainly to the age structure of the population in which a large proportion of the biomass was in slow-growing older individuals that did not efficiently produce fish flesh. It is clearly evident from their data that a substantial amount of production occurred during the winter months which was not accounted for in their estimates.

Considering these factors, whitefish production in the Logan River would appear unusually low. It should be pointed out, however that the whitefish in the study area were approaching the downstream limit of their range in the Logan River. Their total production, while not only reflecting growth rates, also reflects the relative abundance of whitefish in the study area. These factors, combined with limited

Table 37. Whitefish production estimates for period June 1970 - May 1971.

Source	Production $g/m^2/yr$	
	Above 7-Mile Creek	Below 7-Mile Creek
Gonadal production	.8007	.1507
Juvenile production[a]	1.0502	1.1178
Adult production	2.0277	.3912
Total production	3.8786	1.6597
Gonadal production/Total Production %	20.6	9.1

[a]Juveniles were fish in their first and second years of life.

spawning success in the study area would suggest that this section of the river is at best only marginal habitat for mountain whitefish.

Brown trout

Brown trout population estimates made during the study are presented in Figure 31. During the summer of 1970 the brown trout declined steadily in abundance as water levels in the study area dropped. Although no population estimates were made after normal flows were restored in September, there was no noticeable increase in abundance following the increased flow. The population appeared to decline steadily through the winter and early spring. With the onset of the spring runoff, an increase in the population was noted suggesting movement downstream with high water. As water levels subsided the population likewise declined and remained relatively constant throughout the summer. There appeared to be a slight decline in the population during the fall of 1971, possibly associated with an upstream spawning migration. Brown trout movement at this time was predominately upstream.

The seasonal production pattern in brown trout (Figure 32) was very similar to that of the whitefish. A net negative production occurred during the summer months in both 1970 and 1971. Production was low during the fall and winter and rose to a peak in April and May. Total net

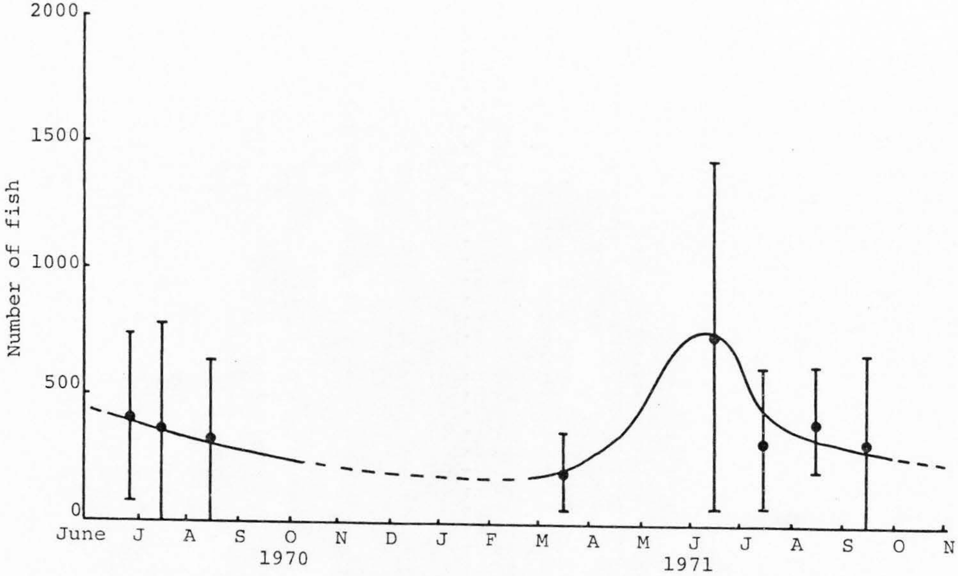

Figure 31. Brown trout population curve in the Logan River above 7-Mile Creek during 1970 and 1971.

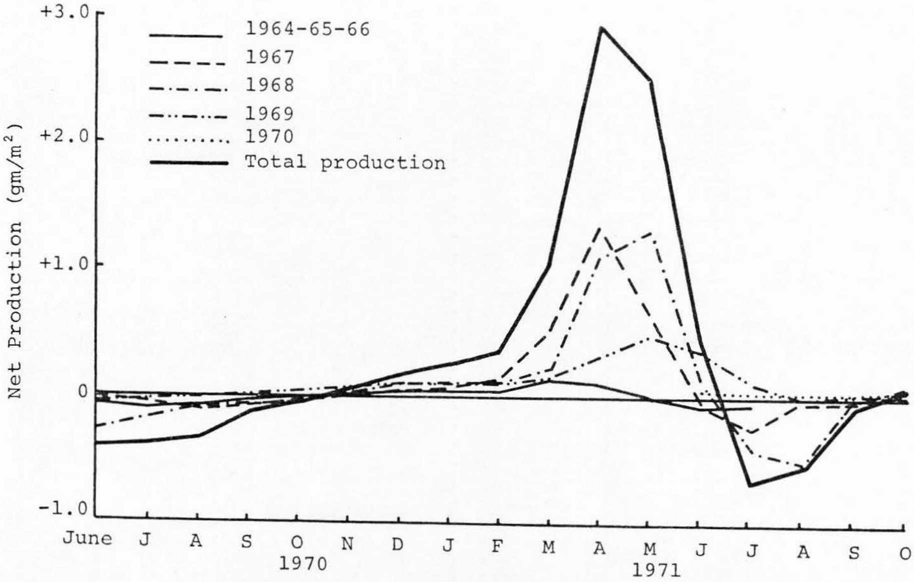

Figure 32. Production curves of brown trout year classes in the Logan River above 7-Mile Creek.

production of somatic tissue for the period June 1970 to May 1971 was 5.8821 gm/m^2/yr (Table 38).

Pre and post spawning total length-gonad weight relationships for male and female brown trout are shown in Figures 33 and 34. Gonadal production estimates based on the algebraic differences of these regression lines are presented in Table 39. The same assumptions made in estimating gonadal production in whitefish were made in estimating gonadal production in the brown trout. Considerable error is likely in the estimation of gonadal production of the male brown trout because of the small number of post spawning fish collected. The estimate should probably be considered minimal.

Adding gonadal to somatic tissue production results in a total estimated production of 5.9413 gm/m^2/yr for the period June 1970 through May 1971. Gonadal production accounted for approximately .99 percent of the total production for the year. Allen (1951) attributed 2.3 percent of total brown trout production to gonad production in a New Zealand stream while Frost and Smyly (1952) reported 3.2 percent in an English pond trout population.

Because of the low numbers of brown trout below 7-Mile Creek the population size (and production) in this area was difficult to estimate. If, however, it is assumed that the biomass collected is proportional to the standing crop and that standing crop is proportional to production (as was

Table 38. Distribution of production among brown trout year classes for the period June 1970 - May 1971.

Year class	Net production[a] g/m^2/yr	% of total net production
1966	.1362	2.31
1967	2.4588	41.80
1968	2.1787	37.04
1969	1.1084	18.84
Total	5.8821	100.00

[a]Somatic tissue only.

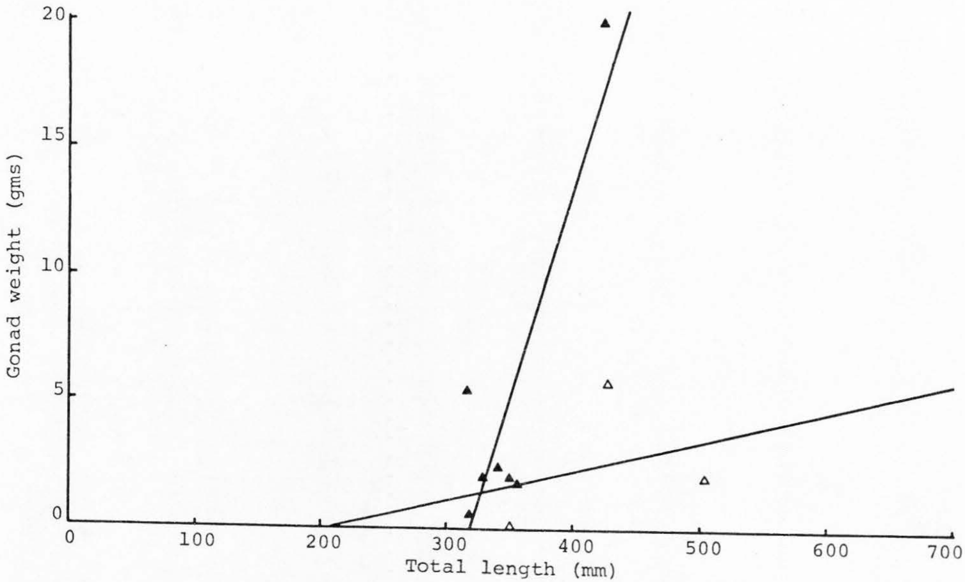

Figure 33. Total length-gonad weight relationship in pre and post spawning male brown trout. Solid dots indicate pre spawning fish, open dots indicate post spawning fish.

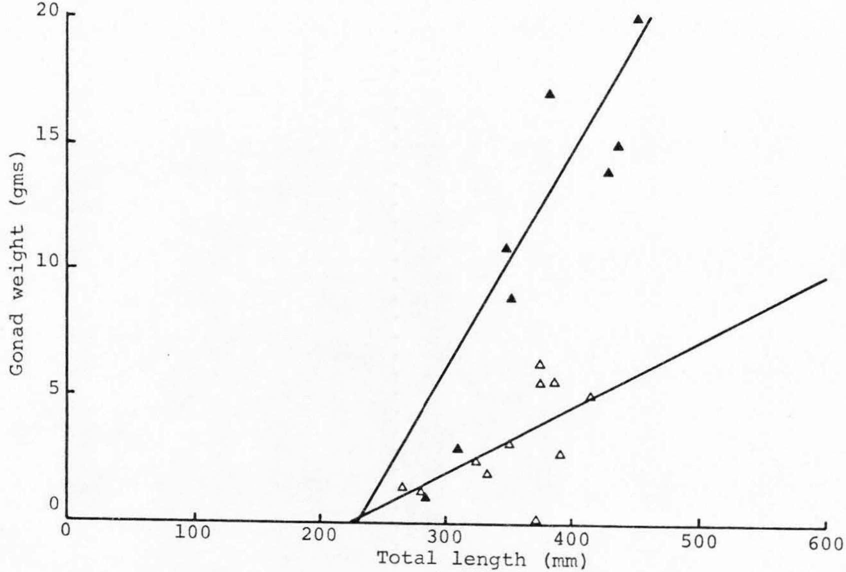

Figure 34. Total length-gonad weight relationships in pre and post spawning female brown trout. Solid dots indicate pre spawning fish, open dots indicate post spawning fish.

Table 39. Estimated brown trout gonad production in the Logan River 1970-1971[a].

	Pre and post spawning weight loss (gms)	Estimated spawning population[b,c]	Estimated total weight loss due to spawning (gm/m^2)
1970			
Females	7.89	138	.0407
Males	6.90	72	.0185
1971			
Females	7.89	164	.0484
Males	6.90	86	.0222

[a]Estimates for above 7-Mile Creek only.
[b]Sex ratio 1 male; 1.9 female.
[c]Based on mid November population.

done by Chapman (1966) in estimating total fish production in Wyland Lake, Indiana, from the data of Gerking (1962)) a production estimate of .83 gm/m^2/yr can be obtained for the river below 7-Mile Creek. Most of the production below 7-Mile Creek probably occurs in the upper sections of this area. Very few brown trout were collected in the lower most sections of this area.

In a classical study of stream fish production, Allen (1951) estimated brown trout production at 54.7 gm/m^2/yr. Mann (1965) and Chapman (1966) however indicate possible errors in Allen's estimates which would lower the value to about 45 gm/m^2/yr or less, still one of the highest estimates made for any species. A production estimate of 10-18 gm/m^2/yr was made by Horton (1961) for brown trout in an English brook. The estimate of 5.94 gm/m^2/yr in the Logan River would appear low for the species. As with the whitefish, the brown trout in the study area are approaching the lower limit of their range in the river and it would appear that they are at the lower extent of suitable habitat for the species. Factors most likely limiting brown trout production in the river are food, suitable spawning habitat and cover.

The brown trout population in the river did not exhibit a classical population structure with the age 0 fish being numerically dominant and older fish declining smoothly in abundance. Age 0 brown trout were very seldom seen or collected during the study. Even during the extremely low water in August 1970 when the river was thoroughly sampled, small trout were rarely in evidence. Limited seining in the river also failed to demonstrate their presence in the river in any substantial numbers. Limited spawning success in the study area probably accounts for this noticeable absence of young trout. Suitable spawning habitat was not abundant in the study area, most gravel being heavily silted except in areas of high water velocity. Although no redds were observed in the river nor were any trout eggs recovered during gravel screening efforts, there was evidence that some spawning was occurring. The observed changes in pre and post spawning gonad development alone would support this contention. Furthermore, on November 25, 1971 a 557 gram female brown trout was collected in section 2 whose stomach was replete with recently spawned trout eggs. It appears that although spawning occurs, it is limited in extent and survival is very low. It is suspected that the majority of brown trout in the study area were recruited from upstream reaches of the river, probably during the spring runoff. It would be of interest to see what effect the dredging and channelization which occurred upstream from the study area in the fall of 1971 will have on the future recruitment of brown trout in the study area.

Carp

The estimation of carp production in the river was complicated somewhat by the inability to distinguish individual year classes in the population. In order to do this a means of aging each fish would have been needed. Scales were not found suitable for aging the carp. Had other parts of the fish been used, high mortalities could have been expected and it is likely the population would have been nearly extirpated during the first few months of the study.

Because small carp were seldom encountered and the majority of the larger fish were fairly uniform in size it was possible to base production estimates for the population on the mean production of recaptured fish during given time intervals. It was assumed that during short time intervals production by fish lost through natural mortality would not significantly increase the estimate of production. The very low annual mortality rate observed in the carp population ($a = .3093$) would further support this contention.

Production estimates were made during four time intervals roughly encompassing the following periods: summer 1970, fall 1970, spring 1971 and summer 1970 to summer 1971. Mean weight changes were calculated for all fish tagged and recaptured during the respective time intervals. Net production during the period was estimated as the product of mean weight change and the mean population size (Table 40).

Table 40. Net production estimates for carp above and below 7-Mile Creek based on weight changes of tagged fish.

	July-September 1970		August-March 1970-1971		February-July 1971		July-October 1970 July-October 1971	
	Above	Below	Above	Below	Above	Below	Above	Below
Average individual weight change g/day	-.888	-.811	-.116	+.076	+1.973	+2.090	+.777	+.942
(N)	(24)	(9)	(20)	(60)	(3)	(2)	(17)	(7)
Mean population size	1866	1403	1024	2217	2981	1301	1987	1635
Net population weight change g/day	-1657	-1137	-118	+168	+5881	+2719	+1543	+1540
Time period in days	90	90	150	150	120	120	360	360
Mean days between captures	(26.7)	(31.6)	(106.1)	(98.6)	(152)	(138.5)	(363.7)	(359.0)
Net estimated production for period g/m^2	-5.58	-3.31	-.66[a]	+.81[a]	26.04[b]	10.55[b]	21.08	18.19

[a]Production based on 150 day period October-February.
[b]Production based on 120 day period March-June.

Population abundance curves for carp above and below 7-Mile Creek are shown in Figures 35 and 36. The annual pattern of carp production appears to be quite similar to that observed in the whitefish and brown trout populations. A net negative production occurred during the summer months, production was negligible during the fall and early winter and was at its highest level during the spring. Total estimated annual production of somatic tissue above 7-Mile Creek based on these three periods (19.80 $gm/m^2/yr$) agreed quite closely with the estimate (21.08 $gm/m^2/yr$) based on known weight changes of fish which were recaptured after a oneyear period. Below 7-Mile Creek the agreement was not as good. The estimates here were hampered by small sample size. As a result it is suspected that the discrepancy was due to an underestimate of abundance in the lower reach of the river.

Gonadal production estimates for female carp are presented in Table 41. Spawning was assumed to occur in June and early July. There was no significant difference in the slopes or means of the pre and post spawning gonad weight-total length relationship in the male carp ($F_{1,23} = .002$ and $F_{1,24} = 3.83$ respectively at the 95 percent confidence level). Gonadal production in the male carp was therefore considered negligible. The gonad weight-total length regressions for both male and female carp are shown in Figure 37.

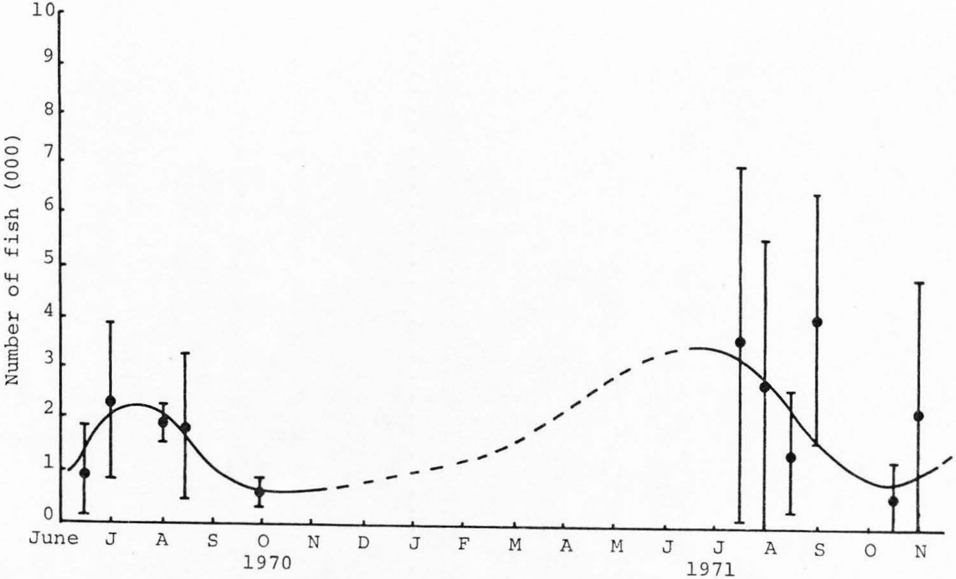

Figure 35. Carp population curve in the Logan River above 7-Mile Creek during 1970 and 1971.

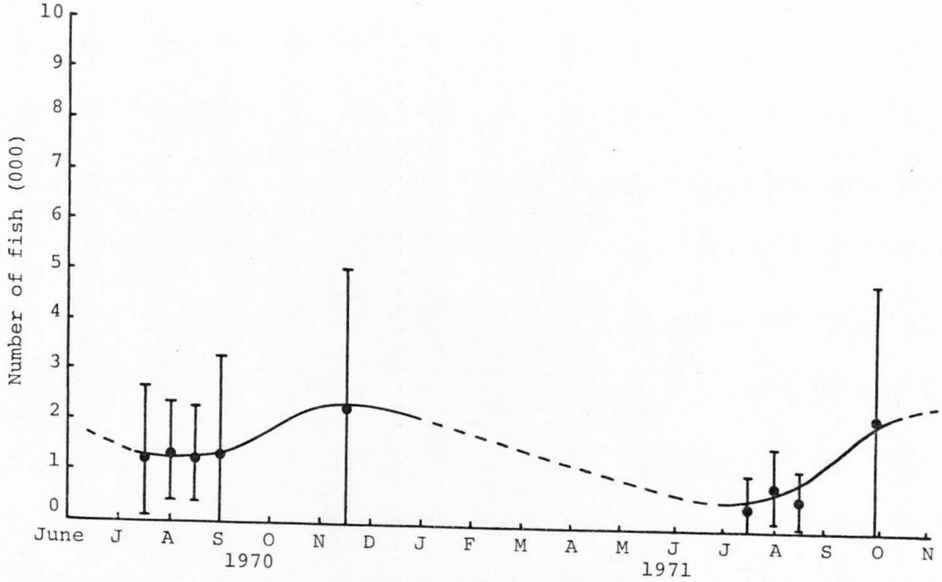

Figure 36. Carp population curve in the Logan River below 7-Mile Creek during 1970 and 1971.

Table 41. Estimated gonad production of female carp in the Logan River 1970-1971.

	Pre to post spawning weight loss (gms)	Estimated spawning population[a]	Estimated total weight loss due to spawning (gm/m^2)
1970			
Above 7-Mile Creek	91	900	3.06
Below 7-Mile Creek	91	835	2.45
1971			
Above 7-Mile Creek	91	1738	5.92
Below 7-Mile Creek	91	339	.99

[a]Sex ratio 1 male : 1.092 females.

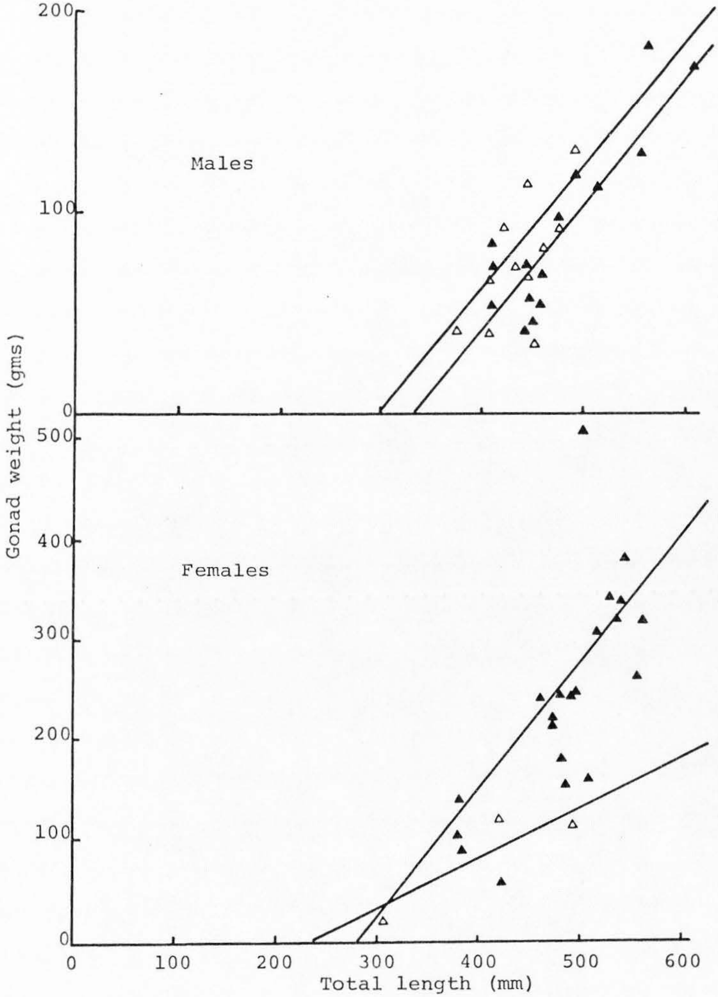

Figure 37. Total length-gonad weight relationships in pre and post spawning carp. Solid dots indicate pre spawning fish, open dots indicate post spawning fish.

Adding the estimated gonadal production to the production of somatic tissue results in a total production of 22.86 $gm/m^2/yr$ above 7-Mile Creek and 10.45 $gm/m^2/yr$ below for the period July 1970 to July 1971. Since extended and multiple spawnings of carp have been reported (Carlander, 1969) it is conceivable that the negative production in the summer of 1970 was the result of weight losses due to shedding of gonadal products. The magnitude of this loss is quite similar to the estimated production during the summer.

Not many estimates of production of non-game fish species have been made. Surprisingly enough, an estimate of carp production under Utah conditions can be obtained. Robel (1962), in a study of growth rates of carp in a bay on the Bear River delta, presented weight increases of fish held in enclosures for periods of up to three months between May and October during 1959-60-61. Fish were weighed when placed in the 2500 ft^2 pens and when removed. They were similar in size to those found in the Logan River, ranging from 1135 grams to 6174 grams. Densities in all cases were less than found in the Logan River. No mortalities occurred in the pens used for making the estimate.

Production estimates based on Robel's data ranged from 1.34 gm/m^2 to 3.67 gm/m^2 with an average for the three summers of 2.61 gm/m^2. From his description of the study area it would appear to be a highly productive environment, being rich in vascular aquatic vegetation. While these values are higher than those in the Logan River for a comparable time period, they are considerably lower than the estimated production in the Logan River for the spring months.

In unfertilized natural waters Viosca (1935) reported carp production ranging from 11.2 to 39.0 $gm/m^2/yr$. In ponds fertilized with domestic sewage he reports annual production as high as 99.7 to 157.0 gm/m^2. From this it appears that carp production in the Logan River is only somewhat below if not comparable to other estimates from natural habitats.

In spite of their slow growth rate, carp accounted for a large proportion of the total annual production in the Logan River. It appears that their abundance was more important in determining their total production than was their growth rate. Hunt (1966) came to the same conclusion in production studies on a Wisconsin brook trout population.

Utah sucker

For reasons already discussed it was not possible to obtain an estimate of the size of the population of suckers in the study area. Without some knowledge of the population size it is very difficult to obtain an estimate of production. Some insight into the seasonal pattern of production can be gained however from an examination of the weight changes that occurred in recaptured fish. In Figure 38 the

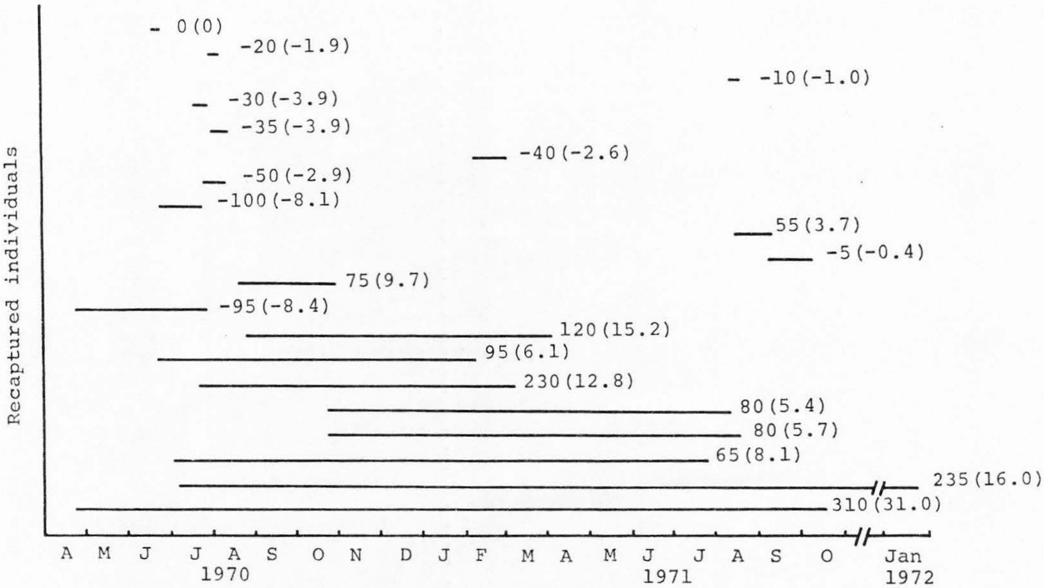

Figure 38. Time intervals between initial tagging and recapture of Utah suckers. Numbers to right of each line are weight and percent changes during the time interval.

time interval between tagging and recapture of all recaptured suckers and their respective weight changes are shown. From this figure a production pattern similar to that of the whitefish, brown trout and carp is evident.

A net negative production occurred during the summer of 1970. Although based on only three recaptures, the same trend in the summer of 1971 is suggested. A seasonal peak in production cannot be clearly discerned from Figure 38 however individual production appears to be somewhat higher during the fall than in the spring.

For suckers at large for almost one year (mean of 339 days at large) the mean individual growth increment was .522 gm/day. This is about 60 percent of the mean of .859 gm/day observed in the carp. Based on their relative abundance in the collections, the biomass of suckers amounted to approximately 20 percent of the carp biomass. Because of the functional similarity of the carp and sucker populations, with large fish predominating, a very rough estimate of sucker production can be made if again, as Chapman (1966) assumed, production is proportional to biomass and as I assume, biomass collected is proportional to biomass present. Assuming that carp production in the study area is approximately 20 $gm/m^2/yr$, sucker production would therefore be on the order of 2-3 $gm/m^2/yr$. Because of the assumptions made, this is probably an overestimate.

Without an estimate of population size total gonadal production cannot be determined. In any respect, individual estimated weight losses due to spawning amounted to 63.1 grams in the females and 26.0 grams in the males.

Other species

During the study fifteen other species were collected which accounted for approximately 4.59 percent of the total numbers and 1.16 percent of the biomass. The majority of these fish were collected in 7-Mile Creek. Because of the small size of most of these fish and their low abundance in the study area it is unlikely that they would contribute a significant amount to the total production in the river. It is therefore probable that production of whitefish, brown trout, carp and suckers approximates total fish production in the river.

The Fish Population and Pollution Abatement in the Logan River

The effects of the sewage discharge in the Logan River and its subsequent abatement following the construction of the oxidation ponds by the City of Logan have clearly effected the fish population in the river as well as other components of the river community. Invertebrate communities are particularly susceptible to alteration in structure and composition when exposed to pollution. Because many fish species present in the river are sight feeders, a slight change in the composition of the invertebrate forage base could have a profound effect on their distribution and abundance. The tubificidae and chironomids common in polluted waters are often not available to many fish as food because of their burrowing habits. Slight organic pollution may therefore actually reduce the amount of food available to fishes by eliminating some of the normal fauna, even though it may actually increase the number of invertebrates per unit area of river bed (Hynes, 1966). It is very probable that the changes in species composition which occurred with the onset of the pollution were influenced by this phenomenon. This could have been particularly significant in the virtual extirpation of the Utah chub population and the increase of carp in the river.

Just as the pollution altered the river biota, its abatement in 1968 likewise produced a change in the then established fish population structure as the river recovered from the excessive organic load. In spite of this it is doubtful that the full complement of native fishes will ever return to the river considering the introduction and establishment of highly adaptive and competitive exotic species such as the carp, rainbow and brown trout and the other seemingly irreversible changes which have occurred on the watershed.

Fish movements generally did not appear to have been greatly altered by the pollution abatement. In the whitefish this was probably a reflection of the relatively low numbers below 7-Mile Creek both during the present study and Matthews' study in 1966. Brown trout, on the other hand demonstrated quite different movement patterns following the abatement of the sewage discharge. Their movements appeared less extensive than in the pre-abatement period, this being attributed to an improvement in water quality below 7-Mile Creek. Without a knowledge of the previous movement patterns of the other species present in the river it is difficult to surmise how they have responded to the pollution abatement. The movement patterns noted in this study for carp and suckers indicate that their movements were not greatly different from those reported in other similar studies suggesting perhaps that no identifiable response, at least during this study, occurred in relation to the improved water quality below 7-Mile Creek.

The effect of the pollution abatement on fish growth was quite variable. Growth of brown trout and whitefish appear to have improved since 1968 whereas carp growth, and to a lesser extent, sucker growth, have declined somewhat. These growth rate changes are consistent with the previously described theory that organic pollution can cause an increase in forage types which are most suitable for non-sight feeding fishes such as carp and suckers. Remove the source of pollution and these burrowing forms decline in relative abundance as other forms increase. As a result the forage base for bottom feeding fishes such as carp and suckers would essentially decline while that for the sight-feeders such as trout and whitefish would increase. As tenuous as this argument may be it seems to be one of the more rational explanations of what has occurred in the Logan River following the pollution abatement.

Fish production estimates in the Logan River are compared in Table 42 to several other studies in which total production was measured.

Production in the Logan River is quite comparable to that in other western streams containing mixed fish populations and is of the same order of magnitude of several other fish production estimates.

Although no estimates of fish production were made prior to the pollution abatement in the river, a comparison can be made with primary production estimates for the river made by Beers (1969) and the fish production estimates from the present study. If one assumes constant gross ecological efficiencies of 10 percent between trophic levels (Slobodkin, 1960) a very rough estimate of potential fish production in the river for the period prior to the pollution abatement can be made. Beers estimated net primary production in the river to be 380 gm $O_2/m^2/yr$. In terms of energy units this equals 1330 $Kcal/m^2$ (conversion factor 3.5; McIntire and Phinney, 1965). If one percent of net production is converted into fish biomass at the third trophic level potential fish production should have been about 13 $Kcal/m^2/yr$. Beers' estimates

Table 42. Comparison of fish production estimates in the Logan River and selected waters ($g/m^2/yr$). Taken in part from Gerking, 1967.

Water	Species	Production	Reference
Logan River, Utah	Mountain whitefish	3.87	-
		1.65	-
	Brown trout	5.94	-
		.83	-
	Carp	22.86	-
		10.45	-
	Utah sucker	2-3	-
Lemhi River, Idaho	Rainbow Trout	2.39	Goodnight and Bjornn, 1971
	Mountain whitefish	7.10	
	Sculpin	.99	
	Dace	.81	
	Chinook salmon	3.04	
Deer Creek, Oregon	Coho salmon Cutthroat trout Sculpin	16	Chapman, 1965
2 Michigan ponds	Bluegill sunfish Pumpkinseed sunfish Redear sunfish	18.1	Hayne and Ball, 1956

Table 42. Continued

Water	Species	Production	Reference
Horokiwi stream, New Zealand	Brown trout	54.7	Allen, 1951
Walla Brook, England	Brown trout	10-18	Horton, 1961
Shelligan Burn, Scotland	Salmon Brown trout	6.5-11.1 7.7-12.3	Egglishaw, 1970
River Thames, England	Roach Bleak Perch Dace Gudgeon	42.6	Mann, 1965
Lawrence Creek, Wisconsin	Brook trout	9.3-10.6	Hunt, 1966
River Thames, England	Bleak	91.4 58.8	Matthews, 1971
	Roach	28.1 15.7	
	Dace	5.2	
	Gudgeon	28.9 3.6	

were based on the entire study area and included areas both above and below 7-Mile Creek. A weighted estimate of fish production for the entire river in the present study is approximately 23.5 $gm/m^2/yr$. Assuming potential energy stored in growth approximates to 1 Kcal for every gram of fresh weight increase (Mann, 1966), this then equals 23.5 $Kcal/m^2/yr$.

Because Beers' estimates were based on production of benthic algae on artificial substrates which were highly suitable for algal colonization, they probably represent a maximum estimate of autochthonous production. It is unlikely that production on the natural substrate in the river would be as high. In any respect, it appears that fish production in the river is greater now than it was during Beers' study. While it cannot be positively demonstrated that the abatement of the sewage discharge was responsible for the apparent increased fish production in the Logan River, it remains as one of the more plausible explanations of this increase.

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APPENDICES

Appendix A

Summary of Numbers and Biomass of Fish Collected in the Study Area in 1970-71-72

Species	Number collected	% of total collected	Mean weight (gms)	Biomass collected (gms)	% total biomass collected
Whitefish	3863	49.94	148	571,724	14.18
Carp	2146	27.74	1264	2,712,544	67.28
Utah sucker	691	8.93	794	548,654	13.60
Brown trout	681	8.80	224	152,544	3.78
Rainbow trout	61	.78	257	15,677	.38
Cutthroat trout	32	.41	295	9,440	.23
Black bullhead	158	2.04	85	13,430	.33
Yellow perch	8	.10	86	688	.01
Green sunfish	46	.59	53	2,438	.06
Bass	4	.05	58	232	.005
Black crappie	3	.03	121	363	.009
Utah chub	19	.24	86	1,634	.040
Red shiner	5	.06	7	35	.0008
Brook trout	2	.02	410	820	.0200
Speckled dace	4	.05	3	12	.0002
Grayling	3	.03	300	900	.0200
Mountain sucker	2	.02	20	40	.0009
Goldfish	1	.01	199	199	.0040
Mottled sculpin	5	.06	5	25	.0006
Total	7734			4,031,399	

Appendix B

Trophic Condition Factors for Logan River Study Area 1970-1971

	Station								
Year	1	2	3	4	5	6	7	8	7-Mile
1970	.829	.808	.993	.918	.956	1.434	1.790	1.960	1.875
1971	.404	.339	.414	.435	.581	.514	.916	1.237	1.512

Appendix C

Estimated Population Size $\hat{N}$, Mean Biomass $\bar{B}$ (g/m^2) and Net Production P (g/m^2) of Whitefish Year Classes Above 7-Mile Creek[a]

	1964-65-66			1967			1968			1969			1970[c]		
Month	$\hat{N}$	$\bar{B}$	P	$\hat{N}$	$\bar{B}$	P	$\hat{N}$	$\bar{B}$	P	$\hat{N}$	$\bar{B}$	P	$\hat{N}$	$\bar{B}$	P
June 1970	254	377	-.0478	168	356	-.3493	92	219	-.1479	149	87	-.0078			.5545
July	174	372	-.0161	157	308	-.0831	81	181	-.0171	204	86	-.0502			.0874
Aug.	66	369	.0069	108	294	.0158	111	177	.0600	170	80	.0000			-.0346
Sept.	37	372	.0117	69	298	.0304	70	192	.0116	78	80	.0786			.0442
Oct.	68	377	.0258	125	305	.0483	103	195	.0095	88	101	.1071			-.1194
Nov.	97	384	.0428	184	312	.0834	111	197	.0142	78	130	.0544			-.1513
Dec.	116	393	.0601	231	321	.0663	101	200	.0085	52	149	.0223			-.1359
Jan. 1971	129	404	.0726	264	327	.0368	89	202	.0152	32	161	.0061			-.0288
Feb.	142	416	.1024	286	330	.0129	81	206	.0323	23	166	.0025			.0061
Mar.	145	432	.0588	295	331	.1052	80	215	.0646	33	168	.0052			.2460
Apr.	148	441	.1502	295	339	.0328	90	232	.1431	44	171	.0312			.4527
May	158	463	.3608	294	364	.7418	109	264	.2642	63	184	.1215			.2106[d]
June	165	513	.3761	289	421	.5473	140	311	.1889	90	219	.1633			
July	148	567	.0597	197	472	-.0342	184	337	-.0446	158	248	-.0636	300	90	.1541
Aug.	32	582	-.0086	109	467	-.1734	216	332	-.1579	319	242	-.3136	834	96	.0907
Sept.	23	575	-.0616	95	429	-.1832	118	311	-.1197	194	215	-.2437	526	99	.0402
Oct.	163	560	-.3472	202	401	-.2477	182	293	-.2725	228	189	-.2236	376	101	.0134
Total Production[b]			.8282			.7413			.4582			.3709			1.1315
% Total Production			23.4			20.9			12.9			10.5			32.1

[a] somatic tissue only

[b] for period June 1970-May 1971

[c] 1st 12 months estimated by exponential growth model of Ricker and Forester (1948)

[d] 1st 15 days of May only

Appendix D

Estimated Population Size $\hat{N}$, Mean Biomass $\bar{B}$ (g/m^2) and Net Production P (g/m^2) of Whitefish Year Classes Below 7-Mile Creek[a]

	1964-65-66			1967			1968			1969			1970[c]		
Month	$\hat{N}$	$\bar{B}$	P	$\hat{N}$	$\bar{B}$	P	$\hat{N}$	$\bar{B}$	P	$\hat{N}$	$\bar{B}$	P	$\hat{N}$	$\bar{B}$	P
June 1970	26	377	-.0045	61	356	-.0908	57	219	-.0665	110	87	-.0027			
July	29	372	-.0035	53	308	-.0222	48	181	-.0054	54	86	-.0091			-.0516
Aug.	42	369	.0027	43	294	.0035	34	177	.0096	37	80	.0000			-.0474
Sept.	13	372	.0026	10	298	.0031	6	192	.0006	6	80	.0053			.0046
Oct.	19	377	.0061	17	305	.0059	7	195	.0007	9	101	.0146			-.0348
Nov.	34	384	.0104	34	312	.0119	15	197	.0020	20	130	.0172			-.0048
Dec.	44	393	.0163	46	321	.0097	26	200	.0021	34	149	.0157			-.0045
Jan. 1971	46	404	.0174	52	327	.0050	37	202	.0056	45	161	.0082			.0354
Feb.	42	416	.0208	50	330	.0016	48	206	.0156	54	166	.0036			.0846
Mar.	37	432	.0102	46	331	.0116	57	215	.0337	56	168	.0052			.2091
Apr.	32	441	.0225	42	339	.0325	63	232	.0745	49	171	.0195			.4357
May	30	463	.0460	37	364	.0626	77	264	.1373	42	184	.0442			.2217[d]
June	26	513	.0369	30	421	.0434	98	311	.0613	35	219	-.0146			
July	16	567	.0139	22	472	-.0050	47	337	-.0064	33	232	-.0035	157	100	.0000
Aug.	40	582	-.0138	39	467	-.0369	30	332	-.0141	74	230	-.0367	309	100	-.0489
Sept.	80	575	-.0332	19	429	-.0131	10	311	-.0039	56	213	-.0550	182	94	-.0309
Oct.	54	560	-.0385	9	401	-.0051	3	293	-.0015	51	182	-.0258	82	87	.0252
Total Production[b]			.1470			.0344			.2098			.1217			.9961
% Total Production			9.7			2.2			13.9			8.1			66.0

[a] somatic tissue only

[b] for period June 1970-May 1971

[c] 1st 12 months estimated by exponential growth model of Ricker and Forester (1948)

[d] 1st 15 days of May only

Appendix E

Estimated Population Size $\hat{N}$, Mean Biomass $\bar{B}$ (g/m^2) and Net Production P (g/m^2) of all Brown Trout Year Classes Above 7-Mile Creek[a]

	1966			1967			1968			1969			1970		
Month	$\hat{N}$	$\bar{B}$	P	$\hat{N}$	$\bar{B}$	P	$\hat{N}$	$\bar{B}$	P	$\hat{N}$	$\bar{B}$	P	$\hat{N}$	$\bar{B}$	P
June 1970	74	1.37	-.0820	156	2.15	-.0286	183	2.06	-.2769	83	.41	-.0128			
July	57	.89	-.1041	101	1.29	-.0822	150	1.49	-.1907	110	.53	-.0155			
August	35	.47	-.0805	58	.69	-.1313	124	1.10	-.1393	147	.59	-.0130			
Sept.	21	.27	-.0207	38	.41	-.0837	106	.85	-.0805	145	.55	.0000			
October	16	.22	-.0055	32	.34	-.0176	94	.72	-.0321	127	.46	.0102			
November	15	.21	.0005	34	.40	.0070	86	.66	.0150	102	.38	.0390			
December	16	.23	.0136	45	.54	.0365	83	.66	.0329	74	.31	.0427			
Jan. 1971	16	.26	.0295	57	.70	.0731	81	.70	.0749	55	.27	.0412			
February	17	.36	.0923	64	.88	.1491	79	.77	.0911	43	.28	.0551			
March	21	.56	.1705	69	1.31	.5130	78	.97	.2216	42	.48	.1205			
April	24	1.10	.1225	77	3.10	1.3818	86	2.26	1.1041	69	1.51	.3147			
May	47	1.60	.0000	138	4.61	.6417	159	4.45	1.3589	204	3.45	.5263			
June	53	1.19	-.1297	122	3.38	-.0158	190	5.01	.1891	334	4.43	.3899	120	.69	.0589
July	24	.38	-.0956	56	1.31	-.2527	150	3.51	-.4083	292	3.44	.1321	143	.75	.0413
August				16	.33	-.0814	94	2.09	-.5012	166	2.17	.0126	122	.75	.0282
Sept.				7	.12	-.0102	79	1.53	-.0661	116	1.62	.0000	131	.81	.1296
October							69	1.26	.0193	94	1.36	.0039	134	.85	.0238
Total Production[b]			.1362			2.4588			2.1787			1.1084			
% Total Production			2.31			41.80			37.04			18.84			

[a] somatic tissue only

[b] for period June 1970-May 1971

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